MBMG 472

Compilation of Landslide Location Maps and Index for Identification of Slide-Prone Areas: A Pilot Study for the Butte District

by

Edith M. Wilde, Kenneth L. Sandau,
Patrick J. Kennelly, and David A. Lopez

Montana Bureau of Mines and Geology

for

Montana Department of Transportation

2002

PREFACE

DISCLAIMER STATEMENT

This document is disseminated under the sponsorship of the Montana Department of Transportation and the United States Department of Transportation in the interest of information exchange. The State of Montana and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Montana Department of Transportation or the United States Department of Transportation.

The State of Montana and the United States Government do not endorse products of manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document

This report does not constitute a standard, specification, or regulation.

ALTERNATIVE FORMAT STATEMENT

The Montana Department of Transportation attempts to provide reasonable accommodations for any known disability that may interfere with a person participating in any service, program, or activity of the Department. Alternative accessible formats of this document will be provided upon request. For further information, call (406)444-7693 or TTY (406)444-7696.

ACKNOWLEDGEMENTS

This study was funded under a State standard agreement for nonprofit institutions, cost reimbursement contract as Montana Department of Transportation project #8150, CFDA No. 20.205.

Collaboration with MDT personnel was a valuable asset to the completion of this project. In addition, thanks and recognition should be given to the MBMG personnel who participated in the earlier (1985-1986) USGS project. Faith Daniels performed and organized the literature search for published landslide locations and information. Mervin J. Bartholomew provided valuable guidance and recommendations during the air photo, airborne reconnaissance, and field-mapping portions of the project. In addition, he mapped faults and some of the landslide locations that were included in the initial project data. Mike Stickney provided addition information on fault locations and seismic data.

Discussions with and reviews by Edmond Deal greatly improved the text of this report. Additionally, personnel in the MBMG Information Services Division and the MBMG Computer Services Division were invaluable to the completion of this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Montana Bureau of Mines and Geology, with support from the Montana Department of Transportation (MDT), has completed a pilot study and compilation of landslide data for MDT's District 2 (Butte/Bozeman area) in southwestern Montana. A total of 4,640 landslides within District 2 have been identified and included in the database developed during the project. The GIS coverages derived from the database enable identification of areas containing high concentrations of landslides, and when combined with other data such as geologic maps, the underlying causes and probable triggers can be identified for many areas. The database structures and procedures designed in this project can be expanded to cover additional areas or Districts if further work is undertaken.

The landslides included in this project were located by field mapping, airborne reconnaissance, aerial-photograph interpretation, and from literature references. They are compiled by location, type, geologic aspect, and size into a database that supports GIS coverages. Locations were originally plotted on from three to five 1:250,000-scale maps sheet , and then each map was scanned into a GIS coverage. Each coverage required extensive editing to eliminate any duplicate information or movement outlines. Once the shape files/coverages were complete and combined into a single coverage, the attributes for each location were entered. At a minimum, the information for each location includes the basic landslide classification (type of material, type of movement) and the location of the movement (in both latitudes/longitude and state plane coordinates). It is important to note that landslides less than 500 feet (150 meters) in the longest dimension cannot be shown because of the map scale

Of the 4,640 landslide locations identified, the material involved was classified as earth in 1,922 landslides (41.5 percent), as debris in 2,556 landslides (55 percent), and as rock in 162 (3.5 percent) of them. The most important movement types identified are slide and flow. The largest number of landslides were identified as slides, 2,759 (59.5 percent), 1,813 were identified as flows (39 percent), 54 were identified as composite or compound (1.2 percent), and for 14 (0.3 percent), the movement or material could not be determined.

A priority rating was assigned to each area containing clusters or large numbers of landslides. The report was loosely based on the number of objects that could be affected if renewed or additional movement occurred. The possible risk was assessed against the other clustered areas within the same1:250,000- or 1:100,000-scale area. A scale of 1-5 was used with one as the highest priority indicating that more detailed investigation including a hazard assessment should be done. All parts of District 2 have clustered landslide areas, however, the Ennis 1:100,000-scale quadrangle area is considered overall to have the highest priority.

The landslides in District 2 are not limited to any specific formations. However, formations containing volcanic materials, because of the ash and clay content, and young (Cretaceous age) poorly consolidated sediments are particularly prone to landsliding. A strong association was noted between fault locations and landslide locations throughout District 2; fault movement, however, probably is not the triggering mechanism in the majority of cases.

Some of the real causes or factors believed to contribute to the tendency to slide are steep topography, prior-glaciation, bedding orientation, human activities, and natural or anthropogenic stream undercutting. The immediate cause of movement (trigger) is commonly not known, but can include earthquakes, increased moisture or water, and toe excavation. In short, any factor that creates unstable slope conditions, can be an effective triggering mechanism.

1.0 INTRODUCTION

The surface of the Earth is a collection of slopes that are inherently unstable. When material is exposed at the Earth's surface, weathering and erosional processes immediately begin to break it apart and move it. Movement may occur suddenly as catastrophic landslides or rockfalls but more commonly occurs almost imperceptibly as the slow creep of soil down gentle slopes. Recent landslide movements often are the reactivation of smaller sections of older, unstable landslide masses.

Landslides are among the most common geologic hazards in Montana and have caused damage in rural and urban areas of the state. In many of Montana's landslide-prone areas, anything affecting slope condition, such as construction, seismic activity, or increased soil moisture, may cause movement or may reactivate prior movement.

Sudden movements are often spectacular and receive much publicity. A major earthquake in southwestern Montana triggered the Hebgen Lake slide of August 18, 1959, and was responsible for loss of life, property damage, and extensive road damage (Bailey, 1961). However, slower movement can also cause severe problems in developing areas. The effects of the very slow (imperceptible) movements can be seen along many Montana roadways in the form of leaning trees, misaligned fences and walls, and damaged road surfaces and foundations.

Whether caused solely by natural processes or aggravated by human activity, when these events occur in proximity to human-made structures, repairs and remediation can be costly. A small, currently active landslide south of Dillon, for example, is a minor portion of a much larger landslide complex and is proving very costly to the railroad; it could impact Interstate 90 if a larger segment of the slide area should move (McDonald, 2001).

2.0 CURRENT PROJECT

The objective of this project is to present an up-to-date landslide database for MDT's District 2 to delineate susceptible areas and types of movement for planning purposes, and that can be expanded to other areas if the opportunity arises. This corresponds with the long-term goal of MBMG to develop a statewide landslide database.

Both MDT and MBMG realize that to make the information useful to non-specialists, it not only needs to be compiled in a database but also displayed attractively and understandably. The result should be a better understanding of landslide-prone areas, processes, and triggers, and should enable a variety of users to make well informed decisions. This goal was addressed by:

- compiling all currently available landslide locations;
- developing a working classification system for the landslide database;
- creating a database structure that can be readily updated, corrected, and added to;
- capturing all available data in ARC/INFO and converting to shape-file format;
- certifying that each slide is unique and referenced in the database;
- identifying landslide-prone areas (areas containing clustered landslides, appendix A);

- determining key factors that cause movement, such as lithology (appendix B), topography, or structure, which may help in prediction of future problem areas;
- creating GIS layers that incorporate landslides, natural features such as topography, geology, and surface-water hydrology, and cultural features; and
- establishing procedures to make the data publicly available once all approvals have been granted.

The primary products resulting from this project are a landslide database with GIS coverages for MDT's District 2. They will be presented separately for approval to MDT, along with a training session for MDT personnel conducted by MBMG project personnel, covering use of the database and digital products (appendix C).

3.0 BACKGROUND INFORMATION

The Montana Bureau of Mines and Geology (MBMG) initially began a statewide compilation of landslide information as part of a hazard-assessment project in 1985 and 1986 in cooperation with the U.S. Geological Survey (Wilde and Bartholomew, 1986). However, the project was left incomplete and the data unpublished because federal funding for the hazard-assessment program was discontinued. Most of the landslides for that program were identified and delineated by stereoscopic interpretation of aerial photographs. The locations were compiled on either 1:100,000- or 1:250,000-scale maps. Reconnaissance mapping and field checking of the interpreted data were conducted from vehicles or light aircraft. The resulting maps included compilations of already published landslide locations, locations gleaned from other research projects, and new locations identified during the project.

The digital database resulting from the early project (1985–1986) was left incomplete. It included generalized locations and information from previously published sources but no new information. This 2001–2002 project built upon the earlier work, including the database, but did not duplicate it.

4.0 BENEFITS AND USES

Nationwide, financial losses resulting from landslides are in the billions of dollars. In terms of lives and property damage, these losses are large enough to produce significant impacts wherever they occur. Montana's impacts receive less attention than those in highly urbanized areas because of the State's low population density. However, as urbanization and development increase, particularly in the mountainous regions of Montana, the potential for large losses also increases. In addition, natural events such as seismicity, high-precipitation, and flooding, also trigger landsliding and increase the overall threat.

The last 4 years have been notably dry, and it has been more than 4 decades since Montana's last large earthquake. However, these conditions cannot be expected to continue. Even in the absence of these aggravating factors, landslides continue to occur. Because many areas of Montana are undergoing rapid development and growth, the rate of occurrence and the severity can be expected to increase dramatically when more normal weather conditions and seismic activity occur.

If high-risk, landslide-prone areas are identified before further development, it can help prevent loss of lives, minimize property damage, and mitigate damage to existing structures. Development has already occurred in some high-risk areas, but knowledge of the locations and types of movement, and identification of the underlying causes of the earth movement can be used to reduce future problems.

Many, if not most, high-risk areas can be identified on the basis of past landslide activity. Many recent landslides are small, relatively minor events within the boundaries of older, much larger ones. Recognition of the larger framework as well as mapping current landslide locations is paramount to understanding the problem.

The information contained in the database resulting from this study provides the framework of modern and ancient landslide occurrences as well as the most obvious underlying causes of movement for landslides in MDT's District 2. Linkage to a GIS database enables the user to view landslide locations at various map scales and to overlay them on available map coverages, such as roads and other cultural features, topography, shaded relief, and geology. This provides a powerful tool for technical and nontechnical personnel to be able to visualize the information that would otherwise be available only as a tabulation of data or presented on static maps.

For those individuals or agencies that will actively use the database, sufficient information is supplied to suggest the basic causes or mechanisms of the clustered landslide areas identified during this project. MBMG and MDT are obvious potential users of the database; others include civil engineers and architects, university geology departments, corporate and private landowners, corporate and private geologists and engineers, federal agencies, and city, county, and state planning agencies.

The database must be viewed as a work in progress. Many small landslides cannot be shown at the scale of the current maps, and new landslides should be added to the database as they occur or are reported. At the minimum, new map coverages can be used in conjunction with the landslide database as soon as they are available or updated in a GIS.

5.0 RESULTS

This study identified 4,640 landslides (table 1, figure 1) in the area covered by District 2 (figure 2, appendix A). They are somewhat more common and of larger extent in the southern half of the district, and many of them occur within a 5-mile buffer area along District 2 roads. Landslides within about 5 miles of roadways are considered the most important. Five-mile buffers along the routes (figure 3, appendix A) cover a large-enough part of the total area, however, to warrant a simplified inventory of all landslides, rather than those only along the routes. The areas most prone to landsliding (figure 4, appendix A) were assigned priorities (1 being the highest) for probable further movement and possible damage.

The identified total is considerably less than the actual number of movements that must be present, however, primarily due to the size constraints of the map scales used, the dates of air-photo coverage, and the limits of recognition and perception of aerial mapping. Of those included in this study, the material involved in 1,922 landslides has been classified as earth, 2,556 as debris, and 162 as rock. Debris was used as a default category; if a determination of the material in the landslide had not been made, the slide material was classified as debris.

The most important movement types identified for landslides in District 2 are slides and flows (table 1). There are as follows:

- 2,759 identified as slides,
- 1,813 identified as flows,
- 54 identified as complex,
- no landslides identified as falls, topples, or spreads, although they exist at scales that could not be included in this project,
- 14 landslides for which the type of movement was not identified. These are identified in the database by a slash separating the types of movement (slide/flow).

Table 1. Total landslides by material and movement type for MDT's District 2.

Description	Count	Total Area (M^2 x 1,000)	Total Area (Acres x 1,000)	Average Area (M^2 x 1,000)	Average Area (Acres x 10)
Earth slide	1259	237565	58.1	189	50
Earth slide/flow	7	13,106	3.2	1,872	460
Debris slide	1454	395,085	97.3	272	70
Debris slide complex	2	4,930	1.2	2,465	610
Earth flow	651	403,616	100.5	620	150
Earth flow, complex	5	37213	9.2	7,443	1840
Rockslide/flow	46	10881	2.8	237	60
Debris flow	1047	1052378	263.3	1,005	250
Debris and rock flow	6	19496	4.8	3,249	800
Debris flow, complex	47	434117	107.7	9,237	2290
Rock flow	115	73550	19.4	640	170
Rock slide/flow	1	10128	2.4	10128	2380

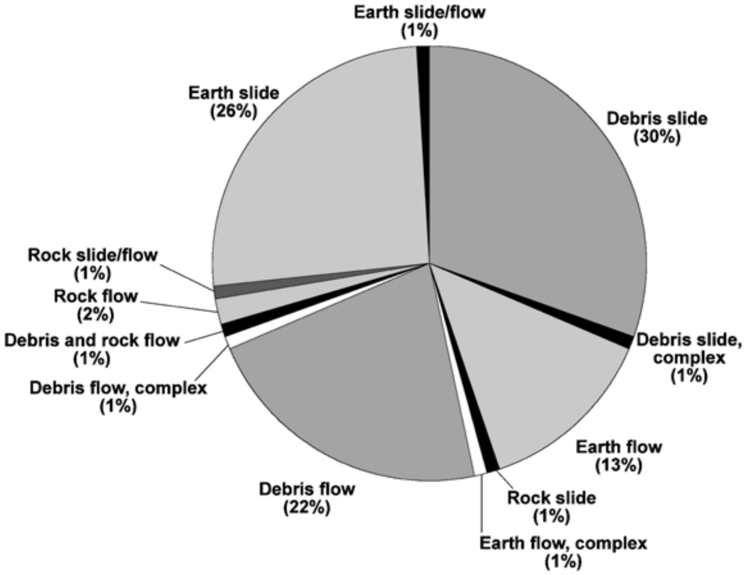


Figure 1. Percentages of landslides by type in MDT's District 2.

6.0 EFFECTS OF LANDSLIDING

Some areas are particularly landslide prone, and the maps in appendix A enable the user to quickly identify them. Overlays of the landslide locations with maps depicting cultural features permit a quick evaluation of the larger features that would be most endangered by renewed or additional landslide movement (table 2). In all map areas demonstrated for District 2, communities, utilities, roads, and waterways are susceptible to landslides. Resorts, lakes, and railroads are also susceptible, although of somewhat more restricted distribution.

Table 2. Features that could be affected by renewed or additional landsliding for each 1:250,000-scale area in the Butte District.

1:250,000	1:100,000	Possibly Affected by Movement						
Scale Map	Scale Map	Communities	Resorts	Utilities	Roads	Lakes	Waterways	Railroad
Ashton				X	X	X	X	
Bozeman	Bozeman	X		X	X	X	X	
	Livingston	X		X	X		X	X
	Gardiner	X	X	X	X		X	
	Ennis	X	X	X	X	X	X	
Butte		X	X	X	X	X	X	X
Dillon		X		X	X		X	X
Dubois		X		X	X	X	X	X
White Sulphur Springs		X		X	X	X	X	

7.0 CAUSES AND TRIGGERING MECHANISMS

Landslides can have several causes (real causes) but only one trigger (immediate cause). In some cases, landslides may occur without an apparent attributable trigger. The landslide triggers have been well documented in only a few of the better known (most catastrophic) slides in Montana. One of those is the 1959 Madison Slide where more than twenty people lost their lives. The immediate cause or trigger for the slide was a 7.1 earthquake centered north of West Yellowstone, Montana. Some of the real causes include adversely oriented bedding, an increase in water content due to higher than normal precipitation, and the presence of steep slopes (Curtiss, 1960; and Curtiss and Knight, 1960).

Table 3 shows those factors most commonly identified as contributors to landslides. Many landslides in District 2 are located along fault traces and/or in areas where folded strata are common, indicating the harmful effects that fracturing or tilting of beds have on slope stability. While earthquakes, which may result from movement along faults, are often the triggering mechanism for landslides, it is unlikely that either the faulting or the folding is recent enough to be the immediate cause. Contributing factors may include the following:

- A few very recent fault movements may have formed scarp faces (broken ground) along which landsliding is prone to occur, in response to unstable slope conditions.
- More landslides probably occur in association with the faulting and folding due to over-

steepening of the strata, displacement of the strata (offsetting beds), and creation of adversely dipping strata (downslope dips) in these areas.

- Differential erosion may also occur, due to the offsetting effect of fault movement on the strata involved.
- Weakening of cohesive units may accompany fault movement; the weakening may allow ground water to saturate the material, or it may provide shear zones that facilitate the movement.

Whether the cause is geologic, morphologic, physical, or human, any one of the factors listed in table 3 can be found at some landslide location in Montana. The most common real causes found in this study for MDT's District 2 are sensitive materials, adverse orientation of geologic strata, fluvial erosion of the toes of landslides, vegetation removal, increased moisture content, and excavation of slope or toe material. The most common triggers appear to be human activity, seismic activity, removal of ground cover, and increased moisture content.

Table 3. Factors that can be considered as contributing to or causing the tendency to landslide in the Butte District.

1:250,000-Scale Map	1:100,000 Scale Map	Factors Contributing to Landsliding							
		Topography	Glaciation	Undercuts	Dips	Faults	Structure	Intrusive	Human Activity
Ashton		X	X	X		X			X
Bozeman	Bozeman	X		X		X	X	X	X
	Livingston	X		X	X	X	X	X	X
	Gardiner	X				X	X	X	X
	Ennis	X		X	X	X	X	X	X
Butte		X	X	X		X	X	X	X
Dillon		X	X	X	X	X	X	X	X
Dubois		X	X	X	X	X			X
White Sulphur Springs		X		X	X	X	X	X	X

8.0 CLASSIFICATION SYSTEM

Use of the modified classification system developed by Cruden and Varnes (1996) worked well for this project (table 4). It allowed assignment of the most basic classification (type of material and type of movement) to the data and provides for addition of other information if it becomes available.

Each landslide in this study was typed/classified using this basic system (type of material, type of movement). For most of the landslides in District 2, little, if any, additional information was available. Appendices D and E provide a more complete discussion of this system and the terminology used.

Table 4. Simplified classification system adopted for use in this study for the landslides located in the Butte District. Modified from Cruden and Varnes, 1996.

Type of Movement	Type of Material		
	Engineering Soils		
	Bedrock	Predominantly Coarse	Predominantly Fine
Fall	Rock Fall	Debris Fall	Earth Fall
Topple	Rock Topple	Debris Topple	Earth Topple
Slide	Rock Slide	Debris Slide	Earth Slide
Spread	Rock Spread	Debris Spread	Earth Spread
Flow	Rock Flow	Debris Flow	Earth Flow
Complex/Composite	Combination of two or more principal types of movement		

9.0 GEOLOGIC DISCUSSION

The following discussion is based on geologic maps produced by either the USGS or the MBMG. There are some differences between the two sources in the abbreviations used and the names for formations/deposits involved. Therefore, the abbreviations and formations/deposits names are taken directly from the geologic maps that were used. Originating formations listed for each area are described in greater detail in appendix B.

9.1 Ashton 1:250,000-Scale Quadrangle (Figure 5, Appendix A):

Only the northwest corner of the Ashton area is located in Montana, and large debris flows and flow/slide complexes dominate it. The occurrence of slides versus flows appears to be random. The locations of debris slides and flows occur most often in the higher, steeper and tree-covered areas. Two areas containing clustered landslides were identified during this project (figure 5).

Area 1 is located in the Gravelly Mountain Range where prior glaciation has strongly affected the topography (figure 5). Steepened slopes caused by glaciation can be related to some landslide locations, and there appears to be a relationship to faulting. The landslides in area 1 tend to cover large areas. Large debris flow complexes, earth flows, earth slides, debris flows, debris slides, rock flows, and rock slides are present. No single formation can be identified as the major source of landsliding (table 5). The originating formations include Quaternary colluvium (Qc), Quaternary pediment gravel (Qtp), Tertiary travertine lake or hot springs deposits (Ttr), Cretaceous Thermopolis Formation (Kt), Cretaceous Mowry Shale (Kt), undivided Cretaceous Mowry Shale and Thermopolis Formations (Kmt), and Archean Marble (Am). This area is located north and upslope from the eastern end of the Centennial Valley where Upper and Lower Red Rock Lakes are located along the course of Red Rock Creek. Part of the eastern extent of the area is located along both sides of State Highway 287.

Table 5. Formations identified as originating landslides in the Ashton 1:250,000-scale area (figure 5).

Ashton 1:250,000-Scale Map	Formations (appendix B)			
	Quaternary	Tertiary	Cretaceous	Archean
	Qa Qtp	Ttr	Km Kmt Kt	Am

Area 2 is south of area 1 and extends across the Continental Divide into Idaho (figure 5). Numerous faults transecting the area, and steep topography caused by prior glaciation, have contributed to instability of slopes in this area. It contains two debris flow complexes, several debris flows, and debris slides. The originating formations include Tertiary travertine lake or hot springs deposits (Ttr), Cretaceous Thermopolis Formation (Kt), Cretaceous Mowry Shale (Km), and undivided Cretaceous Mowry Shale and Thermopolis Formations (Kmt) (table 5). New or renewed movement could affect Upper and Lower Red Rock Lakes and Red Rock Creek and the secondary state road through the valley.

9.2 Bozeman 1:250,000-Scale Quadrangle:

The occurrence of slides versus flows appears to be random. The locations of debris slides and flows occur most often in the higher, steeper- and tree-covered areas. Rock slides occur only on high barren slopes in areas that were probably glaciated. The majority of landslides in this area were classified as earth slides or flows. Although the landslides were originally plotted at 1:250,000 scale, the geology for the area was compiled and mapped at the 1:100,000 scale. The portions of the Bozeman area containing clustered landslide locations are discussed below under each of the four 1:100,000-scale map quadrangles (Bozeman, Livingston, Gardner and Ennis) that are included within the 1:250,000-scale quadrangle.

9.3 Bozeman 1:100,000-Scale Quadrangle (Figure 6, Appendix A):

The majority of landslides in this area were classified as earth slides or flows. This study located 10 areas with clustered landslides.

Area 1 is immediately east of the community of Willow Creek and south of the secondary state road between the communities of Three Forks and Willow Creek (figure 6). It contains both earth slides and earth flows. Area 1 is immediately south of the Southwest Montana Transverse Zone (the zone of faulting crossing Montana from southeast to southwest, transverse to, or across the prevailing structural trend), and two unnamed southeast-trending faults cross it. The originating formation for all the landslides is Tertiary Climbing Arrow Formation (Tca) (table 6). Renewed or additional movement is less likely to cause problems in area 1 than in some of the other areas, but could affect Montana State Highway 2, the community of Willow Creek, Willow Creek or the Jefferson River.

Table 6. Formations identified as originating landslides in the Bozeman 1:100,000-scale area (figure 6).

Bozeman 1:100,000-Scale Map	Formations (appendix B)				
	Quaternary/ Tertiary	Tertiary	Cretaceous	Cambrian	Archean
	QTgr	Tca Tdc Tmva Ts	Kit	Cm Cp	Aamh Aq Aqfg

Area 2 is south of area 1 in the central part of the Bozeman quadrangle (figure 6). It contains both earth flows and earth slides. The eastern extent of area 2 parallels the Madison River. Three southeast-trending faults cross the area, and two folds are located immediately to the west. This area contains both earth slides and earth flows. The originating formation for the landsliding is the Tertiary Dunbar Creek Formation (Tdc) (table 6). Renewed movement could affect the Madison River or the secondary roads in the area.

Area 3 is east of State Highway 287 and southwest of Willow Creek Reservoir (figure 6). It contains both large earth flows and earth slides. The Cherry Creek fault and another unnamed fault cross the area. Two of the earth flows appear to originate in Quaternary and Tertiary gravels (QTgr) and flow through Tertiary sediment or sedimentary rocks (Ts) and down into the Tertiary Dunbar Creek Formation (Tdc) (table 6). The remaining landslides originate in the Tertiary Dunbar Creek Formation. Renewed movement could affect Dry Hollow Creek and Norwegian Creek and tributaries of Willow Creek. Highway 287 and a small reservoir (Willow Creek Reservoir) could also be affected.

Area 4 is in the south-central part of the Bozeman quadrangle along the west side of the Madison River valley (figure 6). It contains both earth slides and large earth flows. Area 4 is crossed by two southeast trending faults; the southernmost fault is the Elk Creek Fault. The originating formations (table 6) include Quaternary and Tertiary gravels (QTgr); Tertiary Dunbar Creek Formation (Tdc) and Archean quartzofeldspathic gneiss (Aqfg). Renewed movement in the area could affect the Madison River course, or State Highway 84.

Area 5 is located in the southeastern corner of the Bozeman quadrangle along the base of the Gallatin Range (figure 6). It contains several large debris flows and slides that appear to have started due to stream undercutting. Faults occur in the area, including a fault located along the base of the mountain front. All of the debris flows in area 5 occur on or near fault traces. The originating formations (table 6) include the Tertiary Madison Valley Formation (Tmva), Cambrian Meagher Limestone (Cm), the Cambrian Park Shale (Cp), and quartzofeldspathic gneiss (Aqfg). This area is upstream from the Gallatin River and renewed movement could affect the tributaries, including Bozeman Creek, which flows through the community of Bozeman. A more-detailed study should be done to assess the risk for the area.

Area 6 is located west of area 5 on the southern edge of the Bozeman 1:100,000-scale quadrangle (figure 6). It contains both earth flows, large debris flows, and earth slides. The Salesville, Elk Creek and Cherry Creek faults cross this area, as do several unnamed faults. The slides appear to be strongly associated with the faulting. The originating formations include (table 6) the Tertiary Madison Valley Formation (Tmva), Tertiary sediment or sedimentary rock (Ts), the Cambrian Meagher Limestone (Cm), the Cambrian Park Shale (Cp), Archean quartzite (Aq), and Archean quartzofeldspathic gneiss (Aqfg). The area is in the upper reaches of the tributaries of the Madison and Gallatin Rivers, and Camp Creek.

Areas 7 and 8 are located west of area 6 and along the southern edge of the Bozeman quadrangle (figure 6). They contain both earth slides and earth flows, and an unnamed fault crosses both areas. The originating formations (table 6) include Archean amphibole and hornblende gneiss (Aamh), and Archean quartzofeldspathic gneiss (Aqfg). Renewed movement could affect Bear Trap and Pole Creeks, tributaries of the Madison River. State Highway 84 could also be affected.

Area 9 is located west of area 8 (figure 6) and contains earth slides and flows. Its originating formations (table 6) include Tertiary sediment or sedimentary rocks (Ts), Cretaceous intrusive rocks belonging to the Tobacco Root Batholith (Kit), and Archean quartzofeldspathic gneiss (Aqfg). Most of the landslides are along Hot Springs and Woods Creeks, just upstream from Norris Hot Springs and State Highway 287.

Area 10 is located in the southwest corner of the Bozeman area, along the Tobacco Root Mountain front (figure 6) and contains both debris slides and flows. Rock flows become prominent higher in the batholith on barren slopes, and the Mammoth Fault crosses the area. The originating formation is a Cretaceous intrusive of the Tobacco Root Batholith (Kit). Renewed movement could affect the drainages of Norwegian and Willow Creeks.

9.4 Livingston 1:100,000-Scale Quadrangle (Figure 7, Appendix A):

The landslides in the Livingston quadrangle are not evenly distributed; an area in the east-central part of the 1:100,000-scale area contains very few. The Cretaceous Hell Creek and Fox Hills Formations crop out in those areas. Many of the slides and flows in the northern and central part of the area seem to have an association with dikes and faults. The steepness of the topography and faulting appear to be the largest factors in landsliding in the southern and western part of the area. The landslides labeled as earth slides or flows are largely located in outcrops of the Tertiary Fort Union Formation. This study identified 14 areas that seem to have clustered landslides. Areas 3 through 8 are associated with the southern flank of the Crazy Mountains.

Area 1 is in the Bridger Mountain Range in the northwest part of the Livingston quadrangle (figure 7) and contains numerous thrust faults and tight folds. Landsliding consists of a debris flow complex, large debris flows, debris slides and earth slides. Because of the topographic steepness and geologic structures, the originating formations (table 7) are difficult to determine at the 1:100,000 scale but include the Cretaceous Sedan Formation (Kse), the Ordovician-Cambrian Snowy Range Formation and Pilgrim Limestone (Ocsp), and the Cambrian Park, Meagher, Wolsey and Flathead Formations (Cpf). Renewed movement could affect the upper tributaries of Bridger Creek and State Highway 86.

Table 7. Formations identified as originating landslides in the Livingston 1:100,000-scale area (figure 7).

Formations (appendix B)								
Tertiary	Tertiary/ Cretaceous	Cretaceous	Jurassic	Pennsylvanian/ Mississippian	Mississippian	Devonian/ Ordovician	Ordovician	Cambrian
Tftr Tmva	TKfu	Kbc Kclf Kco Kcus Ke Kf Kho Kjre Kk Klsr Kmfr Kmi Kse Ktc	Jm	PMpa PMqa	Mm	DOt	Ocsp	Cf Cpf Cpl

Area 2 is in the west-central part of the Livingston quadrangle (figure 7). The area is in the upper reaches of the tributaries of Bracket and Jackson Creeks. Bracket Creek is a tributary of the Shields River, and Jackson Creek is a tributary of the East Gallatin River. The area includes a thrust fault, a normal fault, and several folds, and contains earth and debris slides and earth and debris flows. The undivided Tertiary-Cretaceous Fort Union Formation (Tkfu) is the originating formation (table 7). New or renewed movement is less likely to affect major streams or transportation routes than some other clusters in this area.

Area 3 is in the upper reaches of Cottonwood Creek and its tributaries in the north central part of the Livingston quadrangle (figure 7). It includes a few earth slides a debris flow complex, debris flows and debris slides. There are a few dikes and an intrusive body included in area 3. The largest slide complex originates from an intrusive body and the originating formations (table 7) include Tertiary alkalic intrusives (Tai), and undivided Tertiary-Cretaceous Fort Union Formation (TKfu). New or renewed movement could affect Cottonwood Creek, which is a tributary of the Shields River; the Shields River parallels U.S Highway 89.

Areas 4, 5, 7 and 8 are east of area 3 in the northeastern corner of the Livingston quadrangle (figure 7) in the upper reaches of tributaries of the Yellowstone River. Area 7 contains only earth slides, but areas 4, 5, and 8 also contain earth flows. These areas are crossed by or contain dikes and intrusive bodies. The originating formation is the undivided Tertiary-Cretaceous Fort Union Formation (TKfu). New or renewed movement in areas 7 and 8 could affect the tributary systems of West and East Fork Duck and Little Timber Creeks, tributaries of the Yellowstone River. U.S. Interstate Highway 90 is on the southern side of the Yellowstone River.

Area 6 is north of areas 5 and 8 in the northeast part of the Livingston quadrangle (figure 7). It includes debris flows and slides, and is close to several dikes. The originating formations (table 7) include undivided Tertiary-Cretaceous Fort Union Formation (TKfu), and the Tertiary Tongue River Member of the Fort Union Formation (Tftr). New or renewed movement is less likely to affect streams or transportation routes than in other areas, but this one is in the upper reaches of the Yellowstone River tributaries.

Area 9 is in the southeastern corner of the Livingston quadrangle (figure 7) along the Absaroka-Beartooth Range front. It includes one large debris flow complex, an earth slide complex, debris flows and slides, and earth flows and slides. There are several faults and fold structures in the area. Several of the large debris flows and the complexes are located along the Boulder River or one of its tributaries. Some of the landslides appear to have formed from undercutting; therefore, each separate landslide location may include several formations. These originating formations (table 7) include Cretaceous Cody Shale (Kco), the Cretaceous Frontier (Kf), the Cretaceous Kootenai Formation (Kk), the Cretaceous Mowry Shale through Fall River Formation (Kmfr), the Pennsylvanian and Mississippian Phosphoria, Quadrant, and Amsden Formations (Pmpa), the Mississippian undivided Madison Group (Mm), and the Jurassic Morrison Formation (Jm). New or renewed movement could affect the West and East Forks of the Boulder River and the Boulder River.

Area 10 is northwest of area 9 in the south-central part of the Livingston quadrangle (figure 7). It contains one very large earth slide complex, and earth flows and slides. The large earth slide complex and several other landslides seem to be associated with faults of the Nye-Bowler fault zone. The originating formations are all Cretaceous (table 7) and include the Cody Shale (Kco), the Judith River through Eagle Formations (Kjre), the volcanic rocks of Sliderock Mountain Member of Livingston Group (Klsr), and the Telegraph Creek Formation (Ktc). Area 10 is immediately south of the Yellowstone River. U.S. Interstate Highway 90 and the Burlington Northern Railroad run parallel to the river, and could be affected if renewed movement occurred.

Area 11 is west of area 10 in the south-central part of the Livingston quadrangle (figure 7). There are several faults and a fold structure in this area, and it includes earth slides and flows that are located along stream courses in the drainage system for the Yellowstone River. The originating formations (table 7) include Cretaceous Cody Shale (Kco), Judith River through Eagle formations (Kjre), undivided Jurassic Ellis Group (Je), and Pennsylvanian and Mississippian Phosphoria, Quadrant and Amsden Formations (PMpa). This area is in the upper reaches of the Yellowstone River tributaries and is, therefore, not likely to affect waterways and transportation routes. However, U.S. Interstate Highway 90, State Highway 89, the Burlington Northern Railroad, and the community of Livingston could be affected.

Area 12 is west of area 11 in the south-central part of the Livingston quadrangle (figure 7). It includes numerous thrust faults, additional faulting, and tight fold structures. The eastern extent of the area lies along the Yellowstone River and its tributary, Strickland Creek. It includes one debris flow complex, debris slides and flows, and earth slides and flows. The eastern boundary of the area is parallel to the

Yellowstone River Valley, and the slides located along it include more than one formation due to undercutting. The originating formations (table 7) include Cretaceous Kootenai Formation (Kk), Cretaceous Mowry Shale through Fall River Formations (Kmfr), undivided Mississippian Madison Group (Mm), Devonian-Ordovician Three Forks, Jefferson, and Big Horn Formations (DOt), and the Cambrian Pilgrim Limestone (Cpl). This area is upstream from the Yellowstone River, Montana Highway 89, the Burlington Northern Railroad, and the community of Livingston.

Area 13 is in the southwestern corner of the Livingston quadrangle (figure 7) and includes several faults, including thrusts, and several tight folds that have created steeply dipping beds. The northern extent of the area is parallel to and along both sides of the Yellowstone River. It includes debris flow complexes, and debris flows and slides. The originating formations (table 7) include the Cretaceous Brilliant Creek Formation (Kbc), the Cretaceous lower shale member of the Cody Shale and Frontier Formations (Kclf), the Cretaceous upper shale member of the Cody shale (Kcus), the Cretaceous Mowry Shale through Fall River Formations (Kmfr), the Cretaceous Miller Creek Formation (Kmi), the undivided Mississippian Madison Group (Mm), the Jurassic Morrison Formation (Jm), the Pennsylvanian-Mississippian Quadrant and Amsden Formation (PMqa.), and the Cambrian Flathead Formation (Cf). Since area 13 lies along the Yellowstone River and its tributaries, those waterways could be affected if movement renewed or if new movement occurred. U.S. Interstate Highway 90 and the Burlington Northern Railroad parallel the river, so renewed or new movement could affect all three.

Area 14 is in the west-central part of the quadrangle along the south edge of the Bridger Range (figure 7). The area contains numerous faults, including thrusts, and steep dips. It includes debris flows and slides, two slide complexes and a few earth slides. The originating formations (table 7) include the Tertiary Madison Valley Formation (Tmva), the Cretaceous lower shale member of the Cody Shale and Frontier Formations (Kclf), the Cretaceous Eagle (Ke), Hoppers (Kho), and Telegraph Creek Formations (Ktc). This area is upstream from the East Gallatin River and from Bridger Creek. State Highway 86 parallels Bridger Creek and U.S Interstate 90 parallels East Gallatin River. The Burlington Northern Railroad parallels U.S, Interstate 90. Renewed or new movement could affect either or both of the waterways and any or all of the transportation routes.

9.5 Gardiner 1:100,000-Scale Quadrangle (Figure 8, Appendix A):

The Gardiner 1:100,000-scale area contains most of the Absaroka Mountain Range, Paradise Valley, and part of the northern edge of Yellowstone National Park. Fewer landslides have been identified in this area than in the rest of the Bozeman 1:250,000 map area. Landsliding includes both debris and rock slides, and earth, debris and rock flows. This study identified seven areas that appear to have clustered landslides:

Area 1 is in the west-central part of the Gardiner quadrangle (figure 8). The eastern extent of area 1 parallels the Yellowstone River valley, and landslides occur on both sides of the valley. It contains one very large debris slide/flow complex, large debris flows, and debris slides. It contains some faulting along which some landsliding has occurred. Some of the landslides are located at the change in slope between Paradise Valley and its bordering mountains; others are on tributaries, therefore undercutting may have played a part. There are numerous originating formations (table 8), including Quaternary glacial lake deposits (Qgl), Tertiary Hyalite Peak volcanics, andesite epiclastics (Tae), Tertiary Hyalite Peak volcanic-andesite flows (Tanf), Tertiary basalt (Tba), Tertiary Dacite intrusives (Tdi), Tertiary Colmeyer Creek volcanic-andesite sills (Tgcf), and undivided Tertiary volcanic rocks (Tv), and Permian through Cambrian Mylonite (PCmy). New or renewed movement in area 1 could affect Big Creek, Tom Minor Creek (both tributaries of the Yellowstone) and/or the Yellowstone River. In addition, State Highway 89 runs parallel with the Yellowstone River through Paradise Valley.

Table 8. Formations identified as originating landslides in the Gardiner 1:100,000-scale area (figure 8).

	Formations (appendix B)							
	Quaternary	Tertiary	Cretaceous	Mississippian	Devonian/ Ordovician	Permian-Cambrian	Cambrian	Archean
Gardiner 1:100,000-Scale Area	Qgl Qgt Qs Qyh	Tae Tanf Tba Tdi Tdp Tgcf Tse Tslc Tv	Klf	Mm	DOt	PCmy	Cs	Aga Agn

Area 2 is in the east-central part of the Gardiner quadrangle (figure 8). It is a small area containing three large earth flows. The area is very close to Chico Hot Springs and is located at the slope break between Paradise Valley and the Absaroka-Beartooth Mountains, and along both sides of Emigrant Creek. Numerous faults nearby may have contributed to the landsliding. The originating formations (table 8) include Tertiary dacite porphyry (Tdp) and Permian Cambrian mylonite (PCmy). Due to the proximity of area 2 to a public recreational area (Chico Hot Springs) and a tributary of the Yellowstone River, new or renewed movement could affect both, as well as State Highway 89.

Area 3 is in the north-central part of the Gardiner quadrangle in the sediments of Paradise Valley (figure 8). One fault crosses the area and two more are nearby. It contains three, large debris flows. The originating formations (table 8) include Quaternary glacial till (Qgt), and Archean amphibolites and gneiss (Aga). Renewed movement in the area could affect the secondary road (540) to Chico Hot Springs, or the Yellowstone River, or Montana Highway 89.

Area 4 is in the east-central part of the Gardiner quadrangle in the Absaroka-Beartooth Mountain Range (figure 8). It contains both debris and rock flows, and involves the Boulder River and three of its tributaries. It is immediately south of an area containing intrusive sills and dikes, and north of two fault traces. There are faults and intrusive dikes in the area. The originating formation is Archean gneiss (Agn, table 8). Renewed movement could affect the upper reaches of the Boulder River tributary system and the Boulder River.

Area 5 is in the east-central part of the Gardiner quadrangle between areas 4 and 6 (figure 8). Slopes in this area have been over-steepened by prior glaciation. It contains rock slides, a debris flow and debris slides. There are faults and intrusive dikes in the area. The originating formation is Archean gneiss (Agn). New or renewed movement in this area is not likely to affect any major waterways or transportation routes. It is in the upper reaches of Slough Creek.

Area 6 is in the south-central through southeastern portion of the Gardiner quadrangle (figure 8). Most of the landslides are located along the steep sides of creeks (Pebble, Slough, Buffalo, Hellroaring and their tributaries) in a previously glaciated area. It contains very large debris slides and flows. Three faults cross the area and more are located nearby. Almost all the large landslides in area 6 are in or very near Tertiary volcanics. The originating formations (table 8) include undivided Quaternary sediments (Qs), undivided Tertiary volcanic rocks (Tv), the undivided Mississippian Madison Group (Mm), the Devonian-Ordovician Three Forks, Jefferson, and Big Horn Formations (DOt), and undivided Cambrian sedimentary rocks (Cs). New or renewed movement in this area is unlikely to affect any major waterways or transportation routes.

Area 7 is in the southwestern part of the Gardiner quadrangle. The landslides are located along the tributaries of the Yellowstone River and the Gardiner River (figure 8). The area contains a large earth flow, debris slides, and very large debris flows, and is in a region containing numerous faults and intrusive dikes that appear to induce or contribute to landsliding. The numerous originating formations (table 8) include Quaternary glacial till (Qgt), Quaternary Huckleberry Ridge tuff (Qyh), Tertiary Hyalite Peak volcanics, breccia vent facies (Tae), Tertiary dacite intrusives (Tdi), the Tertiary Sepulcher Formation (Tse), the Tertiary Lost Creek Tuff member of the Sepulcher Formation (Tslc), and the Cretaceous Landslide Creek through Frontier Formations (Klf). One very large debris flow lies immediately west of and upslope from the community of Gardiner, and the Yellowstone and Gardiner Rivers. The earth flow and a debris slide are located immediately east of Montana Highway 89, and the remaining landslides are located on or near tributaries of the Yellowstone River. New or renewed movement could affect any or all of these features.

9.6 Ennis 1:100,000-Scale Quadrangle (Figure 9, Appendix A):

The Ennis 1:100,000-scale area contains several very large flows. The debris flows are concentrated in the mountainous areas. The earth flows and debris slides tend to be concentrated in the valley areas. This project identified 19 areas in the Ennis quadrangle that appear to have clustered landslides, but there are also many large slides and flows outside of the clustered areas.

Area 1 is in the north-central portion of the Ennis quadrangle in the Madison Range (figure 9). It lies along the east shore of Ennis Lake and along the Madison River north (downstream) of the lake. It contains large debris slides and earth flows. A thrust fault and several other faults cross or are in the area. Due to the faulting, there are numerous originating formations (table 9), including Quaternary alluvial terrace gravels (Qat), Quaternary colluvium including glacial deposits (Qgt), undivided Tertiary sedimentary rocks (Ts), undivided Permian sedimentary rocks (Ps), the Mississippian-Devonian Three Forks and Jefferson Formations (MDtj), Archean amphibole (Aam), and Archean mylonite of the Crooked Creek shear (At). If new or renewed movement begins, Ennis Lake, the Madison River, and U.S. Highway 287 could be affected due to proximity to this area.

Table 9. Formations identified as originating landslides in the Ennis 1:100,000-scale area (figure 9).

Ennis 1:100,000-Scale Area	Formations (appendix B)							
	Quaternary	Tertiary	Cretaceous	Permian	Mississippian	Mississippian/ Devonian	Cambrian	Archean
	Qaf Qat Qc Qgr Qgt Qta	Tc Tg Ti Ts Tvt Tv Tw	Kco Kd Kev Kf Kk Km Kmt Ks Ktc	Ps	Ml Mm	MDtj	Cm Cmf	Aam Agn Agp Ama At Aq

Area 2 is east of area 1 in the north-central part of the Ennis quadrangle area in the Madison Range (figure 9). It is across the range divide from area 1. It contains only three debris slides; one of them is very large. Steep topography and dips appear to have induced the landsliding because there are no faults shown nearby. The originating formations (table 9) include Quaternary glacial sediments or rocks (Qgt), undivided Permian sedimentary rocks (Ps), Archean amphibole (Aam), and Archean quartzite (Aq). New or renewed movement could affect the upper reaches of Cherry Creek, but no major waterways or transportation routes.

Area 3 is in the west-central part of the Ennis quadrangle (figure 9). It contains a large slide complex located on both sides of Montana Highway 287 where the community of Virginia City is located. In addition, area 3 contains debris flows and slides and an earth flow. One fault crosses the southern part of the area and another is adjacent to the northern part of the area. In addition, an intrusive dike and a fold structure are nearby. The originating formations (table 9) include undivided Tertiary volcanic rocks (Tvt), Tertiary felsic tuff (Tw), undivided Permian sedimentary rocks (Ps), and Archean gneissic rocks (Agn). Continued or renewed movement in this area would further affect State Highway 287, Alder Creek and the community of Virginia City.

Area 4 is directly west of area 3 in the west-central part of the Ennis quadrangle (figure 9) and it extends on both sides of State Highway 287. No faults are near the area, but most of the slides appear to be located on tributaries of the Madison River. The originating formations (table 9) include undivided Tertiary volcanic rocks (Tvt), undivided Permian sedimentary rocks (Ps), and Archean gneissic rocks (Agn). New or renewed movement of the area could affect State Highway 287 and possibly the Madison River.

Area 5 is directly south of area 4 in the west central portion of the Ennis quadrangle (figure 9). The eastern part of the area is near the west side of the Madison River and most of the landslides appear to be located on tributaries upslope from the river. The western extent of the area is in the upper reaches of

Alder Creek. There are several faults located in area 5, and it contains one very large earth flow complex, additional smaller earth flows, and earth slides and debris flows. The originating formations (table 9) include Quaternary colluvium and glacial gravels (Qgr), undivided Tertiary gravels (Tg), undivided Tertiary volcanic rocks (Tvt), undivided Permian sedimentary rocks (Ps), the Mississippian Lodgepole Formation (Mm), the Mississippian-Devonian Three Forks and Jefferson Formations (MDtj), and Archean tonolitic gneiss of the Crooked Creek Formation (At). New or renewed movement could affect the Madison River, the community of Virginia City and State Highway 287.

Area 6 is located in the central part of the Ennis quadrangle on the west-facing front of the Madison Range (figure 9). It is upslope of and along tributaries of the Madison River and contains large debris slides and flows. The flows are limited to the Cretaceous formations. Numerous thrust faults with overturned formations in the area appear to have contributed to landsliding. Additional faults, intrusive dikes, tight fold structures, steep dips and topography also affect the area. Due to extensive faulting, there are numerous originating formations (table 9), including the Cretaceous Mancos Shale (Km), the Cretaceous Dunkleburg Formation (Kd), Cretaceous Virgelle member of the Eagle Formation (Kev), the Cretaceous Kootenai (Kk) and Mowry through Thermopolis Formations (Kmt), the Mississippian Mission Canyon Lodgepole Formation (Mm), the Mississippian-Devonian Three Forks and Jefferson Formations (MDtj), and Archean amphibolite (Aam). New or renewed movement or additional landsliding could affect Jack Creek and North Fork Bear Creek, tributaries of the Madison River. This area is also upstream from a public resort area (Big Sky ski area, including the resort communities of Big Sky Mountain Village and Big Sky Meadow Village.)

Area 7 is located east of the northern end of area 6 in the central portion of the Ennis quadrangle (figure 9) in the Madison Range, south of Spanish Peaks. For this area, the landsliding is north of State Highway 64 except in the southeastern part of the area where it crosses to the south side of the highway immediately east of the Big Sky Meadow Village. It contains two very large debris slide/flow complexes and numerous debris slides and flows. Most of area 7 is south of a major thrust fault and is in Cretaceous rock, but the area does extend north across the thrust where landsliding occurs in much older units. The area also contains fold structures, and appears to have been previously glaciated. The steepness of the topography and steep dips in the area also contribute to the area's tendency to move. The numerous originating formations (table 9) include Quaternary glacial till and other sediments (Qgt), the Cretaceous Dunkleburg Formation (Kd), the Cretaceous Virgelle member of the Eagle Formation (Kev), the Cretaceous Frontier (Kf) and Kootenai Formations (Kk), the Cretaceous Mowry Shale through the Thermopolis Formation (Kmt), and Archean granite porphyry of the Hellroaring Creek Formation (Agp). Renewed or additional landsliding could affect the rapidly growing area around the ski resort (Big Sky), the communities of Big Sky Meadow Village and Big Sky Mountain Village, the Middle Fork and West Fork of the Gallatin River, and State Highway 64. A more detailed study should be done for this area.

Areas 8, 9, 15, and 16 are located south and east of areas 6 and 7 (figure 9). Landslide types and originating formations in these areas appear to be similar to those in the southern part of area 7. Area 8 is immediately southwest of the ski resort; area 9 is immediately south and west of area 8. Areas 15 and 16 are south of area 9, and 16 is on the southern-central edge of the Ennis area. The northern parts of area 9 cross State Highway 64 in two locations, and the western part of area 9 crosses State Highway 191. They both contain very large debris slide/flow complexes, debris flows, and debris slides. Area 9 contains a few earth slides where it crosses State Highway 64 near Big Sky Mountain Village. These areas are almost totally in Cretaceous rock and lie south of a major southwest-trending thrust fault crossing the area. Additional faulting is present in area 9, immediately north of another southwest-trending thrust fault. Only one fold is mapped south of and parallel to the northernmost thrust fault. The originating formations (table 9) include Quaternary colluvium (Qc), Quaternary glacial till and other sediments (Qgt), Cretaceous Mancos Shale (Km), the Cretaceous Dunkleburg (Kd), and Kootenai Formations (Kk), the Cretaceous Mowry Shale through the Thermopolis Formation (Kmt), the Cretaceous Telegraph Creek (Ktc), and the Cody Shale Formations (Kco). Renewed or additional landsliding in any of the areas could affect the rapidly growing area around the ski resort (Big Sky), the communities of Big Sky Meadow Village and Big Sky Mountain Village, the Middle and West Forks of the Gallatin River, State Highways 64 and 191. A more-detailed study should be done for the area around the resort and along the major highways.

Areas 10 through 14 are located in the east-central part of the Ennis area in the Gallatin Range (figure 9). The west edge of area 10 is close to State Highway 191 and the Gallatin River but does not cross it. Area 14 is along both sides of the river and the highway. One thrust fault nearly crosses area 10 and another is immediately southwest of area 11. These areas are in regions where generally older formations crop out. Many of the landslides have formed along stream courses, and may have formed by undercutting. They all contain large debris flows and debris slides; area 13 contains a very large slide complex. The originating formations (table 9) include Quaternary colluvium (Qc), Quaternary glacial till and other sediments (Qgt), Upper Pleistocene diamicton (Qta), Tertiary alkalic intrusives (Tc), Tertiary diatreme intrusives (Ti), undivided Cretaceous sediments (Ks), undivided Permian sediments (Ps), the Mississippian Mission Canyon Lodgepole Formation (Mm), and the Cambrian Big Horn Dolomite, and Red Lion Formation (Cm). Renewed or additional movement could affect the Gallatin River and State Highway 191. Many of the largest landslides are in the upper reaches of the tributaries of the Gallatin River.

Area 17 is in the south-central portion of the Ennis quadrangle on the western slope of the mountains (figure 9) and contains a debris slide and several earth flows. Two faults and numerous springs are in or near the area. The originating formations (table 9) include Quaternary alluvial fan sediments (Qaf), Quaternary glacial till and other sediments (Qgt), undivided Tertiary sediments and sedimentary rocks (Tg), Tertiary undivided volcanics (Tv), and undivided Permian sediments and sedimentary rocks (Ps). This area is upslope from the Gallatin River and State Highway 287, so renewed or additional movement could affect either or both.

Area 18 is west of and across the valley from area 17, in the south-central portion of the Ennis quadrangle on the eastern slopes of the Gravelly Range (figure 9). Landsliding occurs primarily along Ruby and Johnny Creeks, both are tributaries of the Gallatin River. Area 18 is in a region with closely spaced thrust faults and contains two large earth flows and several earth slides. The originating formations (table 9) include Quaternary colluvium and glacial gravels (Qgr), the Mississippian Lodgepole member of the Big Snowy Group (Ml), the Cambrian Meagher Limestone(Cm), the Cambrian Meagher Limestone and Flathead Sandstone (Cmf), and Archean marble (Ama). This clustered area is upslope from State Highway 287 and on tributaries of the Gallatin River; so renewed movement could affect both.

Area 19 is in the southwest corner of the Ennis area in the Gravelly Mountain Range (figure 9). The landslides are upslope and on or near tributaries of the Ruby River. The area contains several thrust faults and additional faults, and the topography is steep. The area contains two large earth flows, three large debris flow complexes and several debris slides. The originating formations (table 9) include Quaternary colluvium and glacial gravels (Qgr), the Cretaceous Mancos Shale (Km) and Kootenai Formation (Kk), the Jurassic Morrison Formation (Jm), the undivided Jurassic-Triassic Ellis Group through Dinwoody Formation (JTred), and undivided Permian sedimentary rocks (Ps). Because this area is located in the upper reaches of the Ruby River, new or renewed movement could affect the tributaries, the river, and the Ruby Reservoir.

9.7 Butte 1:250,000-Scale Quadrangle (Figure 10, Appendix A):

The distribution of slides versus flows appears to be random in this area, and the locations of debris versus earth landslides do not correspond to topography or steepness, nor to vegetative cover. Outcrops of volcanic rocks, regardless of age or origin, correspond to landslide locations. Landslides that could affect transportation routes are scattered along the Interstate and many of the state highways that cross this area. Fourteen areas identified during this study contain clustered landslides.

Area 1 is located along the valley and steep mountainsides of the Clark Fork River, east of the community of Missoula (figure 10). This area is located along both sides of Interstate Highway 90; the Burlington Northern Railroad parallels the Interstate. Two debris flows located at the western end of the area could be of concern to two East Missoula subdivisions. The area contains rock flows and slides as well as rock falls that are too small to show at this scale. The landslides appear in most of the Proterozoic-age formations outcropping in the area (table 10), including the Bonner (Ybo), Garnet Range (Ygr), McNamara (Ym), Mount Shields (Yms), Pilcher (Ypi), and Snow Slip Formations (Ysn). This area should be studied in detail because of its proximity to two major transportation corridors for Montana and the developed area in East Missoula.

Area 2 is in the north central part of the Butte quadrangle on the western side of the Nevada Valley (figure 10). It contains several debris flows and numerous earth and debris slides. The faulting entering the area from the west may indicate structural causes for at least some of the landslides. The originating formations (table 10) include Pliocene and Holocene surficial sedimentary rocks (Qs), Eocene and Oligocene andesite and basalt (Tab), undivided Tertiary sediment or sedimentary rocks (Ts), and the Proterozoic Mount Shields Formation (Yms). The flows in the northern portion of the area could affect State Highway 200. In addition, new or renewed movement in this area could affect State Highway 141, and Nevada Creek and its tributaries.

Table 10. Formations identified as originating landslides in the Butte 1:250,000-scale area (figure 10).

	Formations (appendix B)							
	Quaternary	Tertiary	Tertiary/ Cretaceous	Cretaceous	Cretaceous/ Jurassic	Permian/ Devonian	Cambrian	Proterozoic
Butte 1:250,000-Scale Area	Qs	Tab Tgd Tlc Trv Ts	TKg TKgd	Ka Kem Kg Kgd Kmd	KJs	PDs	Cs	Ybo Yc Ygr Ym Ymb Yms Ypi Yq Ysn Yss

Area 3 is at the southeastern end of Nevada Valley (figure 10). It contains both debris and earth flows as well as earth and debris slides. There is a tendency for landslides to occur on or near fault traces, and on the flanks of the mountains that are commonly capped with Cambrian sedimentary rock. The steepness of the slopes and of the dips in this area may have contributed to the tendency of the material to slide. The originating formations (table 10) include Eocene and Oligocene andesite and basalt (Tab), undivided Eocene through Pliocene sedimentary deposits (Ts), the Proterozoic Garnet Range (Ygr,), McNamara (Ym), Bonner (Ybo), and Mount Shields Formations (Yms), and undivided Cambrian sedimentary rocks (Cs). The flows at the northern end of the area could affect State Highway 141 and Nevada Creek, as well as its tributaries, if renewed movement occurs.

Area 4 is along the portion of State Highway 141 that extends from the community of Finn to U.S. Highway 12 (figure 10). It contains a large rock slide, two earth flows and a large area of earth slides. The area is south of a fault trace and along Flatwillow Creek, indicating that undercutting and the location of fault traces may have contributed to the landsliding. The originating formations (table 10) for all the landslides are Pliocene and Holocene surficial sedimentary rocks (Qs), and undivided Tertiary sedimentary deposits (Ts). New or re-activated landslides could affect the community of Finn, Nevada Creek and State Highway 141.

Area 5 is in the central part of the Butte quadrangle on the north side of Interstate Highway 90 (figure 10). The area contains debris flows and earth slides. Three folds in the area may have contributed to the occurrence of the landslides. The originating formations (table 10) include undivided Pliocene and Holocene surficial sediments (Qs), Eocene and Oligocene andesite and basalt (Tab), undivided Eocene through Pliocene sedimentary rock (Ts), undivided Cretaceous and Jurassic sedimentary deposits (KJs), and undivided Permian through Devonian sedimentary rocks (PDs). Renewed movement of the landslides could affect Bert and Hoover Creeks, the Clark Fork River, Interstate Highway 90, and the two tracks of Burlington Northern Railroad that parallel the Interstate. To the east along the Interstate, an area of debris slides is located immediately north of the small community of Gold Creek and could affect both transportation routes and the community.

Area 6 is in the central portion of the Butte quadrangle, at the southern end of Flint Creek valley (figure 10) and contains rock and earth slides, two large debris slides, and earth flows. The area is highly faulted and the landsliding appears to occur preferentially along fault traces. The originating formations (table

10) include undivided Eocene through Pliocene sedimentary deposits (Ts), undivided Cretaceous and Jurassic sedimentary deposits (KJs), a Proterozoic middle Belt carbonate (Yc), the Proterozoic Snow Slip Formation (Ysn), undivided Snow Slip and Shepherd Formations (Yss), and undivided Cambrian sedimentary rocks (Cs). Landslides occur on both sides of two transportation corridors: a spur of the Burlington Northern Railroad and State Highway 1. Renewed movement in the area could affect both transportation systems, the Clark Fork River, Flint Creek, and the community of Maxville.

Area 7 is in the Deer Lodge Valley immediately north of the community of Deer Lodge (figure 10). It contains two small debris slides and a large debris flow. No faulting is mapped in the area, but proximity to the Clark Fork River indicates that undercutting could have contributed to landsliding, as well as material incompetence. The originating formations (table 10) are undivided Pliocene and Holocene surficial sedimentary rocks (Qs), and undivided Eocene through Pliocene sedimentary deposits (Ts). This area lies on the west side of two transportation corridors: two tracks of the Burlington northern railroad and Interstate Highway 15. New or renewed movement could affect either transportation route, the Clark Fork River and the community of Deer Lodge.

Area 8 is located along the Continental Divide and south of State Highway 12 along Tenmile Creek (figure 10), and contains rock and debris flows as well as debris and earth slides. Faulting at the northern and southern ends of the area appears to have controlled landslide locations there. The positions of the remainder of the landslides are along the creek, which may indicate that undercutting also contributed to movement. Additionally, the topography is steep in the area and some of the formations are volcanic in origin. The originating formations include undivided Pliocene and Holocene surficial sedimentary rocks (Qs), undivided Eocene through Miocene rhyolitic volcanic rocks (Trv), Cretaceous granodioritic rocks (Kgd), Cretaceous Elkhorn Mountain Volcanics (Kem), and undivided Cretaceous and Jurassic sedimentary deposits (KJs). This area is upstream from Helena. If new or renewed movement occurred, it could affect Ten Mile Creek, and U.S. Highway 12 as well.

Area 9 is along both sides of Interstate Highway 15 in the southeast corner of the Butte quadrangle (figure 10) and includes Elk Park valley (Bison Creek), part of the Boulder River valley, and the surrounding mountainsides. There are several northeast-trending faults in the area that may have influenced landsliding in the Elk Park valley. The positions of some of the landsliding along the Interstate and the creek indicate that undercutting may have occurred. Additionally the topography is very steep and volcanic material is present. Landsliding consists of rock and earth flows, and debris slides. There are additional rock falls and slides that were too small to locate at the scale used in the project. The originating formations (table 10) include the Tertiary Lowland Creek Volcanics (Tlc), Cretaceous andesite (Ka), Cretaceous granodioritic rocks Kgd), and the Cretaceous Elkhorn Mountain Volcanics (Kem). Renewed movement of any of the landslides in this area could affect Interstate Highway 15, and Bison Creek, as well as the ranches, homes and power lines located in Elk Park valley. This area is also upstream from the community of Boulder, and further study should be completed to assess the area risk.

Area 10 is located along the southwestern side of Deer Lodge valley (figure 10). It contains debris and earth flows and debris and earth slides. Faulting nearby may have influenced some of the landslide locations. The landslides are located on the steep slopes immediately above the slope break of the valley floor. Due to the faulting, there are numerous originating formations (table 10): undivided Pleistocene and Holocene surficial sedimentary deposits (Qs), undivided Eocene through Pliocene sedimentary deposits (Ts), Tertiary Lowland Creek Volcanics (Tlc), Cretaceous granitic rocks (Kg), undivided Cretaceous and Jurassic sediments (KJs), Proterozoic Middle Belt carbonates (Yc), and the Proterozoic Mount Shields Formation (Yms). This area could affect Racetrack and Lost Creeks; both are tributaries of the Clark Fork River, however the area does not directly affect a major transportation route.

Area 11 is in the south-central portion of the Butte quadrangle (figure 10) and includes numerous debris flows, earth flows, debris slides and earth slides. The landslides occur on the steep mountain slopes on both sides of State Highway 10A and on the north flank of Mount Haggin where the topography indicates prior glaciation. Numerous faults are also present in or near area 11. There are several originating formations (table 10), including undivided Pleistocene and Holocene surficial sedimentary deposits (Qs), undivided Eocene through Pliocene sedimentary deposits (Ts), Cretaceous monzodioritic rocks (Kmd), undivided Cretaceous and Jurassic sediments (KJs), undivided Permian through Devonian sedimentary rocks (PDs), Proterozoic Middle Belt carbonates (Yc), and undivided Cambrian sedimentary rocks (Cs). The need for more detailed study is indicated because any renewed movement could affect State Highway 1, Dutchman Creek, three mine sites, a National Forest campground and the communities of West Valley and Stump Town.

Area 12 is near the southern edge of the Butte quadrangle along the Continental Divide in the Anaconda Range (figure 10) and contains numerous debris slides. The area is steep and contains some faulting; additionally, some of the faults are located along stream courses. The originating formations (table 10) include undivided Pleistocene and Holocene surficial sedimentary deposits (Qs), Eocene granodioritic rocks (Tgd), undivided Tertiary or Cretaceous granite (TKg), undivided Tertiary or Cretaceous granodioritic rocks (TKgd), Proterozoic Belt Supergroup metamorphosed rocks (Ymb), the Proterozoic Greyson Formation (Yg); and the informal Middle Belt carbonates (Yc). This area is located in the upper tributaries of Rock Creek and Mill Creek, but movement is unlikely to directly affect transportation routes, major waterways, or homes

Area 13 includes both sides of State Highway 1, immediately north of Georgetown Lake (figure 10) and contains earth slides and one debris slide. The highway makes a hairpin turn at this location and the terrain is steep. There is also faulting in the area where the landslides occur, and volcanic material is present. The originating formations (table 10) include undivided Eocene through Pliocene sedimentary deposits (Ts), the Proterozoic Bonner Quartzite (Ybo), Proterozoic Mount Shields Formation (Yms), undivided Snow Slip and Shepherd Formations (Yss), and Proterozoic Middle Belt carbonates (Yc). Landsliding is located along the tributaries of Flint Creek, which is a tributary of the Clark Fork River. New or renewed movement could affect State Highway 10A, as well.

Area 14 is along Rock Creek Valley and the southern end of the Phillipsburg valley (figure 10) and contains both debris and earth flows (including one very large debris flow) as well as debris and rock slides. The area is faulted and contains glacial features, as well as volcanic materials. The positions of many of the landslides along stream courses indicates that undercutting could have played a part in the movements. The originating formations (table 10) include undivided Eocene through Pliocene sedimentary deposits (Ts), undivided Eocene through Miocene rhyolitic volcanic rocks (Trv,) and Proterozoic Middle Belt carbonates (Yc), the Proterozoic Mount Shields Formation (Yms), and the undivided Proterozoic Snowslip and Shepard Formations (Yss). New or renewed movement might affect upper Rock Creek, which is a tributary of the Clark Fork River and its tributaries. Movement could also affect State Highway 38.

9.8 Dillon 1:250,000-Scale Quadrangle (Figure 11, Appendix A):

Glacial features characterize the higher mountain regions in the Dillon area. Landslides designated as rock flows in those areas might more correctly be designated as rock fall complexes. There appears to be a correlation between two formations and the landslide locations. The middle Proterozoic Missoula Group (Ym) is the originating formation for numerous landslides, particularly those that are slides. The Pliocene through Eocene Bozeman Group (Tbz) and related valley-fill deposits are another originating formation for numerous slides and flows. There is also a direct correlation to faulting. Many landslides lie along the fault traces throughout the area. Additionally, areas with tight folds and steeply dipping strata tend to contain large numbers of landslides. There are 12 areas in the Dillon 1:250,000-scale area with higher concentrations of landslides than the surrounding areas.

Areas 1 and 2 are in the western part of the Dillon quadrangle and contain slides designated as rock flows (figure 11). These areas are located in high mountainous terrain where glaciation has affected the topography by creating steep-sided valleys. Adversely oriented foliation may also have contributed to the movement in some locales. The originating formations in these two areas (table 11) include Quaternary moraine (Qm), Tertiary granite (Tg), the Tertiary Bozeman Group (Tbmg), Cretaceous foliated hornblende-biotite granodiorite and tonalite (Kfgt), the Proterozoic Lemhi Group (Yl), McNamara Formation (Ym), and Missoula Group (Ymm). New or renewed movement in these areas could affect Big Lake Creek, Moose Creek, or Swamp Creek, but is unlikely to affect major waterways or transportation corridors.

Table 11. Formations identified as originating landslides in the Dillon 1:250,000-scale area (figure 11).

Formation (appendix B)												
Quaternary	Tertiary	Tertiary/ Cretaceous	Cretaceous	Jurassic	Triassic	Jurassic–Mississippian	Pennsylvanian/ Mississippian	Mississippian	Cambrian	Proterozoic	Proterozoic/ Archean	Archean
Qa Qf Qm Qo	Tbmg Tbz Tc Tg Tgtd Tvu	TKb	Kal Kbgg Kgd Ki Kk Kmg	Jm	Tu	JMq	PMu	Mdu	Cu	Yhe Yl Ym Ymm Ynl Yq Ysg Yy Xi	XAb	Am

Area 3 is in the north-central part of the Dillon area and runs along both sides of State Highway 43. It contains primarily earth and debris slides, but there are several large flows as well. No faulting is located in or near the area, but the topography is steep. The originating formations (table 11) include Quaternary older alluvial deposits (Qo), undivided Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), Tertiary granodiorite, tonalite and quartz diorite (Tgtd), undivided Tertiary-Cretaceous granite (Tkg), the Cretaceous Kootenai Formation (Kk), and the Proterozoic McNamara Formation (Ym), and Missoula Group (Ymm). New or renewed movement in this area could affect the Big Hole River, State Highway 43 and State Highway 274.

Area 4 is in the central part of the Dillon quadrangle in Beaverhead National Forest and in the valley created by Wise River (figure 11). It contains several large flows that are probably related to the prior glaciation in the area, and the location of several landslides along Wise River could indicate that undercutting contributed to the movement. Additionally, the topography is steep and adverse bedding or schistosity may have affected the area. The originating formations (table 11) include Quaternary moraine (Qm), Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), Cretaceous biotitic granodiorite and granite (Kbgg), undivided Mississippi and Devonian rocks (Mdu), the Proterozoic McNamara Formation (Ym), and undifferentiated Proterozoic quartzite (Yq). Although this area is high in the mountains of the Beaverhead National Forest, its location along the Wise River drainage could cause problems downstream if new or renewed movement began. State Highway 43, the Big Hole River, and community of Wise River are downstream from this area.

Area 5 lies along both sides of two transportation routes in the north-central part of the Dillon quadrangle (figure 11) and extends along State Highway 43, past its junction with and southward along Interstate Highway 15. It contains disparate proportions of slides and flows, including earth and debris slides and earth and debris flows. Nearby structures and faulting probably contributed to the tendency to move. Volcanic material is present in this area, as well. There are numerous originating formations (table 11), including Quaternary alluvial fan deposits (Qf), Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), undivided Tertiary volcanic deposits (Tvu), Tertiary granodiorite and granitoid rocks

(Tgtd), the Cretaceous Kootenai Formation (Kk), undivided Cretaceous intrusive rocks (Ki), undivided Cretaceous sedimentary rocks (Ks), undivided Mississippian and Devonian rocks (Mdu), undivided Cambrian rocks (Cu), undivided Middle Proterozoic Newland and Lahood Formations (Ynl), early Proterozoic and Archean biotite gneiss (XAb), and early Proterozoic igneous rocks (Xi). New or renewed movement in this area could affect the Big Hole River and its tributaries, State Highway 43, Interstate 15, and Burlington Northern Railroad tracks. Because of the proximity to the major transportation routes, this area could need additional investigation.

Area 6 is located mainly in Beaverhead National Forest (the Highland Mountains) south of the community of Butte (figure 11). Its western edge comes very near Interstate Highway 15, and directly across that highway, there are several large flows. The northern part of the area crosses Interstate Highway 90 and State Highway 2 southeast of Butte. The landslides consist mostly of rock, debris and earth slides but also include a few small flows. The topography in the area is steep and there are numerous intrusive bodies, dikes, and steeply dipping beds throughout this area that probably contributed to the tendency to move. Faulting and other structural features are present in or near the area, and it has been affected by prior glaciation. The originating formations (table 11) include Quaternary alluvial valley fill sediments (Qa), Quaternary alluvial fan deposits (Qf), Quaternary moraine (Qm), Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), Cretaceous alluvium (Kal), Cretaceous granodiorite (Kgd), the Cretaceous Kootenai Formation (Kk), undivided Cretaceous intrusive rocks (Ki), the Cretaceous Montana Group (Kmg), Jurassic Morrison Formation (Jm), undivided Pennsylvanian and Mississippian rocks (PMu), undivided Cambrian (Cu), undivided Proterozoic Helena and Empire Formations (Yhe), and undivided middle Proterozoic Spokane and Greyson Formations (Ysg). New or renewed movement in this area, due to its location, could affect the community of Butte, Interstate Highway 15, Interstate Highway 90, State Highway 2, and tracks of the Burlington Northern Railroad.

Area 7 is in the northeast corner of the Dillon quadrangle (figure 11), and continues slightly into the northwest corner of the Bozeman 1:250,000 quadrangle. It contains both debris slides and debris flows. There are several faults in the area and steep slopes. Steeply dipping formations and the presence of volcanic material may have contributed to landsliding. The originating formations (table 11) include Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), Cretaceous Elkhorn Mountain volcanics (Kem), undivided Permian through Mississippian rocks (PMu), undivided Middle Proterozoic Newland and Lahood Formations (Ynl), and undivided middle Proterozoic Spokane and Greyson Formations (Ysg). New or renewed movement could affect Interstate Highway 15, the community of Whitehall, and the Beaverhead River.

Area 8 is in the southeastern part of the Dillon quadrangle (figure 11), primarily in the Ruby Range where steep slopes and dipping strata contribute to the tendency toward landsliding. There are also numerous faults crossing the area, and many of the landslides appear to be located on or near the mountain-front fault. Most movements are small debris slides, but an earth flow and a few debris flows are also present. The originating formations (table 11) include Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), the Tertiary and Cretaceous Beaverhead Group (TKb), undivided Pennsylvanian and Mississippian rocks (PMu), undivided Mississippi and Devonian rocks (MDu), undivided Cambrian rocks (Cu), Archean marble (Am), and Archean quartzofeldspathic rocks (Aqf). New or renewed movement in this area does not appear to be a direct threat to transportation routes; however, it is located in the tributary systems of the Beaverhead River and the Ruby River drainage, including the Ruby Reservoir.

Area 9 is in the south-central part of the Dillon quadrangle area and south of the community of Dillon (figure 11). It contains numerous large earth flows and extends on both sides of Interstate Highway 15. It appears, in part, to be related to faulting because its northeastern boundary lies near a mountain-front fault zone. It contains mainly large earth flows and a few earth slides. Some of the flows are located along the course of Grasshopper Creek and the Beaverhead River, indicating that undercutting or toe removal contributed to the tendency to slide. Steeply dipping beds and volcanic material are present in this area, as well. The originating formations (table 11) include the undivided Tertiary and Cretaceous Beaverhead Group (TKb), undivided Tertiary volcanic deposits (Tvu), the Cretaceous Kootenai Formation (Kk), undivided Triassic rocks (TRu), undivided Pennsylvanian through Mississippian (PMu) rocks. New or renewed movement of the large debris flows in this area could affect Interstate 15, the Beaverhead River, and tracks of the Burlington Northern Railroad. Because of the location of this area, a further investigation should be completed.

Area 10 is in the south-central part of the Dillon quadrangle (figure 11) and is located along State Highway 278 that runs south from the community of Wisdom and connects to Interstate Highway 15. It contains large earth and debris flows. Some of the flows lie along the courses of tributaries of the Big Hole River; therefore undercutting may have contributed to the movement. The originating formations (table 11) include Quaternary older alluvial deposits (Qo), undivided Pliocene to Eocene Bozeman Group and related valley-fill deposits (Tbz), undivided Cambrian rocks (Cu), and the Proterozoic McNamara Formation (Ym). New or renewed movement could affect the upper reaches of the Big Hole River and State Highway 278.

9.9 Dubois 1:250,000-Scale Quadrangle (Figure 12, Appendix A):

The landsliding in the Montana portion of this 1:250,000-scale area is dominated by large debris and earth flows, particularly in the northeastern quarter of the area. The major causes for the landslides in this area are undercutting by intermittent streams or along lake shorelines, and steepness of the slopes. Some landslides can also be related to faulting along the mountain ranges. There are nine areas identified in this project that contain clustered landslides.

Area 1 is in a valley in the north-central part of the Dubois quadrangle (figure 12). It is associated with outcrops of volcanic rocks, and Tertiary sediments. The landslides begin in the volcanics and move down into the Tertiary sediments. Landsliding in the area consists of earth and debris slides, and earth flows. There is faulting near and in the area, and adversely oriented schistosity. The originating formations (table 12) include Tertiary Medicine Lodge volcanics (Tmlv), undivided Tertiary sediment or sedimentary rocks

(Ts), Archean quartzofeldspathic gneiss (Aqfg), and Archean biotite schist (As). Area 1 is located in the mountains in the tributary system of the Beaverhead River, but movements should not directly affect either waterways or transportation routes.

Table 12. Formations identified as originating landslides in the Dubois 1:250,000-scale area (figure 12).

Formations (appendix B)								
Quaternary	Tertiary	Tertiary/ Cretaceous	Cretaceous	Permian	Pennsylvanian	Pennsylvanian/ Mississippian	Mississippian	Archean
Qgm	Ta Tcv Tmlv	TKb	Kblq	Pp Ps	Pq	PMu	Ml Mm	Aqrg
	Trvp Ts Tsc		Kbm Kt	Pu			Mmd	As

Area 2 is south of area 1 in the north-central part of the Dubois quadrangle (figure 12) at the southern end of the same valley. This area crosses the Continental Divide into Idaho. There is faulting in the area as well as steep topography and volcanic deposits. It contains predominantly large earth and debris flows. The originating formations (table 12) are Tertiary Challis volcanics, (Tcv) and Tertiary sediments (Ts). This area is in the upper reaches of some of the tributaries of the Beaverhead River, but should not directly affect waterways or transportation corridors.

Area 3 is located in the part of the Tendoy Range surrounding the valley of Medicine Lodge Creek and the upper parts of Muddy Creek drainage (figure 12). It contains numerous large debris and earth flows, as well as a few earth and debris slides. Many of the landslides appear to be associated with the extensive faulting in this area. The faulting has cut the area into many small outcrops and makes the determination of originating formations (table 12) difficult at the 1:250,000 scale. Many landslides begin in undivided Tertiary sediments or sedimentary rocks (Ts), and in the numerous Archean formations in the area. Several landslides begin in the higher, steep outcrops and move downward into the Tertiary materials. New or renewed movement in the area could affect Medicine Lodge and Muddy Creeks, which are tributaries of the Red Rock River. Medicine Lodge Creek currently empties into the Clark Canyon Reservoir. The Red Rock River course is parallel with Interstate 15 just south of the reservoir and to the east of this area.

Area 4 is on the north-central edge of the Dubois quadrangle (figure 12) and lies largely within the Clark Canyon drainage and the tributary system of the Beaverhead River. It is also located west of the north end of Clark Canyon Reservoir, and is upstream from both Interstate Highway 15 and the Beaverhead River. The area contains a large slide/flow complex as well as earth and debris flows. Area 4 is a southward continuation of an area on the south edge of the Dillon quadrangle. The originating formations (table 12) include Tertiary rhyolitic pyroclastic rocks of the Dillon volcanics (Trvp), the Tertiary-Cretaceous Beaverhead Group (TKb), undivided Permian (Pu), undivided Pennsylvanian through Mississippian rocks

(PMu), the Mississippian Lodgepole Limestone (Ml), and the undivided Mississippian Madison Group (Mm). New or renewed movement in this area could affect Interstate Highway 15 and tracks of the Burlington Northern Railroad, both of which lie between the landslide area and the reservoir. The reservoir and the Beaverhead River could also be affected.

Area 5 is in the northeastern part of the Dubois quadrangle (figure 12) within the Snowcrest Range. This area consists of steep slopes in previously glaciated topography. The area is also extensively faulted and the strata dip steeply. The area contains numerous large debris-flow complexes, a large debris-slide complex, as well as earth and debris flows and a few earth slides. The flows along the northwest side of the mountains originate in high Permian outcrops. The flows and slides along the southeast side of the mountains originate in Tertiary or Cretaceous outcrops. This area continues into the northwest corner of the Ashton quadrangle. The originating formations (table 12) include Quaternary glacial moraine (Qgm), the Tertiary Sixmile Creek Formation (Tsc), the Tertiary-Cretaceous Beaverhead Group (TKb), the Permian Phosphoria Formation (Pp), and the Pennsylvanian Quadrant Formation (Pq). The southern extent of the area ends just north of Lima Reservoir and the county road into the reservoir area in the Centennial Valley. New or renewed movement could also affect the tributary systems of both the Red Rock and Beaverhead Rivers, and Lima Reservoir. This area should be investigated in more detail.

Area 6 is in the east-central part of the Dubois quadrangle (figure 12) where landsliding occurs in the mountains along the Continental Divide on the southern side of Centennial Valley. The area contains debris flows and debris slides. The originating formations (table 12) include Tertiary andesite (Ta) and Cretaceous Thermopolis Formation (Kt). New or renewed movement in the area could affect the Centennial Valley and, therefore, Lima Reservoir and the homes located in the valley.

Areas 7, 8, and 9 are in the central part of the Dubois area within the Beaverhead Mountains along the northern side of the Continental Divide. There are numerous faults, steep slopes, and steeply dipping beds in all the areas. Area 7 is located south of Interstate Highway 15 and the community of Lima and contains mainly earth flows. All the areas are located within the tributary system of the Red Rock River. Area 8 crosses the continental Divide into Idaho and contains earth and debris flows as well as earth and debris slides. Area 9 consists of earth flows and slides. The originating formations (table 12) include Quaternary colluvium (Qc), Quaternary glacial moraine (Qgm), Tertiary sediments and sedimentary rocks (Ts), Cretaceous Little Sheep quartzite of the Beaverhead Group (Kblq), Cretaceous Monida Sandstone of the Beaverhead Group (Kbm), undivided Pennsylvanian through Mississippian rocks (PMu), the undivided Mississippian Madison Group (Mm) and the Mississippian Mission Canyon Formation (Mmd). New or renewed movement in any of the areas could affect Nicholia, Deadman, and Big Creeks; as well as other tributaries of the Red Rock River which empties into the Clark Canyon Reservoir.

9.10 White Sulphur Springs 1:250,000-Scale Quadrangle (Figure 13, Appendix A):

The northern third and the western third of the White Sulphur Springs quadrangle appear to have few landslide locations. However, during the original compilation (1985–1986), aerial photographic coverage was not available in those areas. Only the locations from the literature and from airborne-reconnaissance were plotted. Additional work should be done in that area to complete the coverage. In the areas of coverage, there are high concentrations of landslides in several locations. These higher concentrations appear to be related to structures such as tight folds, and faults and to steeply dipping beds. The mountainous area immediately north and east of the community of White Sulphur Springs is also affected by stream undercutting. In a few places landslides appear to be related to intrusive bodies, particularly where the intrusive forms the higher areas; landslides tend to be present along the contact of the intrusive body with the underlying formation. The steep fronts of the mountain ranges and smaller areas where steep slopes rise are prone to downhill movement. This study located 17 areas within the White Sulphur Springs quadrangle that appear to have clustered landslide locations.

Area 1 is in the northwestern part of the White Sulphur Springs quadrangle (figure 13). This area has steep slopes, numerous faults including thrusts, steeply dipping beds, and folds that appear to contribute to the tendency to move. It contains both debris flows and slides. This area is located along the course of the Missouri River. The originating formations (table 13) include the Permian Phosphoria and Quadrant Formations (Ppp), undivided Pennsylvanian through Mississippian Phosphoria, Quadrant and Amsden Formations (PMpa), the Mississippian Big Snowy Group (Mb) and Madison Formation (Mm). New or renewed movement in area 1 could affect the Missouri River.

Table 13. Formations identified as originating landslides in the White Sulphur Springs 1:250,000-scale area (figure 13).

Formations (appendix B)											
Quaternary	Tertiary	Cretaceous	Cretaceous/ Jurassic	Jurassic	Permian	Pennsylvanian	Pennsylvanian/ Mississippian	Mississippian	Mississippian/ Ordovician	Cambrian	Precambrian
Qal Qmc	Tg Ts Tv	Kb Kc Kcl Kcs Ke Ketc Kf Khfh Ki Kjr Kk Kmt Ks	KJkmc	Ju	Ppp	Pq	Pmab PMqa PMqab	Mb Mm	MDtjm	Cu	pCb pCn

Area 2 is in the central part of the White Sulphur Springs quadrangle (figure 13). An unimproved secondary road going through Confederate Gulch crosses the east side of this area. It contains one debris flow as well as both debris and earth slides. The landslides in the area are located along stream courses indicating that undercutting may have contributed to the movement. Intrusive bodies, dikes, and faulting are also in or near this area. The originating formations (table 13) include Cretaceous intrusive rocks (Ki), and the Precambrian Newland Formation (pCn). New or renewed movement in this area could affect Camas and Big Birch Creeks, which are tributaries of the Smith River. An unimproved road and a ranger station located on the southeast edge of area 2 could also be affected.

Area 3 is south of area 2 in the central part of the White Sulphur Springs quadrangle (figure 13). The slides are located on the steep eastern face of Mount Baldy and there is faulting present. This area contains one debris slide and several debris flows. The originating formations (table 13) include Quaternary glacial moraine and colluvium (Qmc), Cretaceous intrusive rocks (Ki), and the Precambrian Newland Formation (pCn). New or renewed movement in this area could affect Big Birch Creek, but it is located high in the mountains and is unlikely to affect any major waterways or transportation corridors.

Area 4 is east of area 2 in the central part of the White Sulphur Springs quadrangle (figure 13). It is in the mountains north and east of the community of White Sulphur Springs. The area contains steeply dipping beds as well as faulting. Many of the landslides are located along streams, so undercutting may have contributed to landsliding. This area contains debris slides and flows, and one earth slide. Volcanic deposits are also present in this area. The originating formations (table 13) include undivided Tertiary volcanic deposits (Tv), the Pennsylvanian Quadrant Formation (Pq), the Pennsylvanian-Mississippian Amsden and Big Snowy Formations (PMab), the Mississippian Madison Group (Mm), undivided Cambrian rocks (Cu), and Precambrian biotite gneiss (pCb). New or renewed movement in the area could affect U.S. Highway 12, U.S. Highway 89, tributaries of the Smith River, and the community of White Sulphur Springs.

Area 5 is east of area 4 and in the east-central part of the White Sulphur Springs quadrangle. Both slopes and dips are steep in the area, and there is faulting nearby. Many of the landslides are located along streams or along a road cut in the area, indicating that undercutting contributed to the landsliding. Area 5 contains debris slides and flows as well as earth slides and flows and volcanic deposits. The originating formations (table 13) include the undivided Tertiary volcanic deposits (Tv), undivided Cretaceous Colorado Group (Kc), undivided Jurassic rocks (Ju), the Pennsylvanian through Mississippian Quadrant and Amsden Formations (PMqa), the Mississippian Madison Group (Mm), the Mississippian and Devonian Three Forks through Maywood Formations (MDtjm), undivided Cambrian (Cu), and Precambrian biotite gneiss (pCb). New or renewed movement of area 5 could affect the Musselshell River and U.S. Highway 12.

Area 6 is located east of area 5 in the east-central part of the White Sulphur Springs quadrangle (figure 13). Some of the landslides in area 6 are located along streams, so undercutting may have contributed to movement. This area contains earth and debris slides and two earth flows. Both slopes and dips are steep in the area. The originating formations (table 13) include Quaternary alluvium of modern channels and flood plains (Qal), Tertiary granite (Tg), and the undivided Cretaceous Colorado Group (Kc). New or renewed movement in this area could affect Haymaker Creek, and other tributaries of the Musselshell River.

Area 7 is south of area 4 in the central part of the White Sulphur Springs area (figure 13). It is in an area with steep topography, steeply dipping beds and faulting. There are also intrusive deposits in this area. This area contains debris and earth flows, and debris and earth slides. The originating formations (table 13) include undivided Tertiary sediments or sedimentary rocks (Ts), the undivided Cretaceous Colorado

Shale (Kc), the undivided Eagle and Telegraph Creek Formations (Ketc), undivided Cretaceous intrusive rocks (Ki), the Cretaceous Judith River Formation (Kjr), the undivided Cretaceous-Jurassic Kootenai and Morrison Formations and Ellis Group (KJkme), the undivided Mississippian-Devonian Three Forks, Jefferson and Maywood Formations (MDtjm), and undivided Cambrian rocks (Cu). New or renewed movement in this area could affect U.S Highway 89, State Highway 294, and the upper reaches of the Smith River.

Areas 8, 9, 10 and 11 are east of area 7 and in the east-central part of the White Sulphur Springs quadrangle (figure 13). These areas contain steeply dipping strata and steep slopes. Landsliding in area 8 is located along the course of East Fork Haymaker Creek in older formations. It contains an earth slide and three earth flows. Areas 9, 10, and 11 are associated with intrusive bodies in an area with steep slopes and steep dips. These areas contain earth slides and flows, and occur in Tertiary and Cretaceous despots. Area 10 also contains a large debris flow. The originating formations (table 13) include Tertiary granite (Tg), undivided Tertiary intrusive rocks (Ti), the undivided Cretaceous Colorado Shale (Kc), the Cretaceous Claggett (Kcl), Eagle (Ke), and Judith River Formations (Kjr), undivided Jurassic rocks (Ju), the undivided Mississippian Madison Group (Mm), and the undivided Pennsylvanian through Mississippian Quadrant, Amsden and Big Snowy Formations (Pmqab). New or renewed movement in this area could affect some of the tributaries of the Musselshell River, State Highway 294 and U.S. Highway 12.

Area 12 is southwest of area 11 in the east-central part of the White Sulphur Springs quadrangle (figure 13). It is located along a streamcut and on steep slopes. It contains earth and debris slides. The originating formations (table 13) are the Cretaceous Bearpaw Shale (Kb), and the undivided Cretaceous Hell Creek and Fox Hills Formations (Khfh). New or renewed movement in this area could affect tributaries of the Musselshell River, but the area is located high in the mountains. Movement in it is unlikely to affect any major waterways or transportation corridors.

Areas 13, 14, 15, 16 and 17 are located in the southeastern corner of the White Sulphur Springs quadrangle (figure 13). Three areas (13, 14, 15) are associated with intrusive bodies. All of the areas contain landsliding located along streamcuts, indicating that undercutting played a role in the movement. There is some faulting, and folds are located in or near these areas, as well. In area 17, the landsliding occurs in an area encompassing Elkhorn Ridge that has steep slopes, steep dips, and faulting. These areas contain debris and earth flows, debris slides, and a few earth slides. The originating formations (table 13) include the Cretaceous Cody Shale member of the Colorado Shale (Kcs), the Cretaceous Eagle and Telegraph Creek Formations (Ketc), undivided Cretaceous Frontier (Kf), undivided Hell Creek, Fox Hills (Khfh), and Kootenai Formations (Kk), undivided Mowry and Thermopolis Formations (Kmt), and undivided Cretaceous sediments or sedimentary rocks (Ks). New or renewed movement in these area could affect Fish, Sweet Grass, Haymaker, and Sixteenmile Creeks. Sixteenmile Creek is a tributary of the Missouri River; the other creeks are tributaries of either the Musselshell River or the Missouri River. Parts of areas15 and 17 are upstream from U.S. Highway 89.

10.0 GENERAL OBSERVATIONS

Using the currently available data, some general observations for District 2 were made during this project:

- The landslides in District 2 appear to have a stronger association with faulting than with any specific geologic unit (tables 5–13, appendix B). However, in some areas certain geologic formations or lithologies could be identified as being particularly prone to movement:
    - √ Volcanic rocks, or sediments derived from them, are often the originating lithology for landslides. These sediments often contain ash and clay materials that facilitate movement.
    - √ Where present, poorly consolidated sediments, particularly those of Cretaceous, Tertiary and Quaternary age, appear to have a tendency toward landsliding.
    - √ In the Butte and Dillon 1:250,000-scale areas, Proterozoic-age rocks appear to be prone to landsliding.
- Throughout most of District 2, the types of material identified for each slide or flow appears to generally correspond to well-defined topographic settings:
    - √ Earth slides and flows occur most often in areas of more gentle slopes with less vegetation—the foothills and river courses.
    - √ Debris slides and flows generally occur in the steeper, mountainous areas and in areas covered with vegetation.
    - √ Rock slides and flows occur in previously glaciated high valleys with steep slopes that generally lack vegetative cover, and along other very steep slopes (generally greater than 50 degrees).
- The type of movement (slide or flow) does not correspond to the steepness or the vegetative cover. For most of the area, the distribution seems random.
- Flows and flow complexes tend to cover much larger areas than slides.
- Debris flows tend to be larger than earth flows.

11.0 RECOMMENDATIONS

1. Some of the clustered landslide areas identified during this study (figure 4, appendix A) should receive special attention during planning and construction stages of roads or other projects or developments. In those areas, more detailed studies (risk assessments) should be undertaken that include at the minimum geology, hydrology, triggers, contributing causes, risk assessment, and identification of any necessary mitigation.

2. Table 14 and figures 5–13 (appendix A) show the clustered areas by map sheet and indicate whether further study appears desirable. The clustered areas are color coded to indicate the highest to lowest probability of further movement and possible damage. The ranking of relative priority of further study for each clustered area is rated only against the other clustered areas in that same 1:100,000- or 1:250,000-scale area. Rankings are loosely based on the possible affects of movement for each clustered area, and range from 1 through 5, with 1 as highest and 5 as lowest priority.

Table 14. General priority for additional study of landslide clusters. Rankings of 1 (highest) through 5 (lowest) are relative priorities within each 1:100,000 or 1:250,000-scale quadrangle for landslide clusters.

Ashton		Bozeman								Butte		Dillon		Dubois		White Sulphur Springs	
		Bozeman		Livingston		Gardiner		Ennis									
Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority	Area #	Study Priority
1	3	1	3	1	3	1	2	1	5	1	1	1	5	1	5	1	5
2	3	2	3	2	3	2	2	2	5	2	4	2	4	2	5	2	4
		3	2	3	4	3	3	3	1	3	4	3	2	3	4	3	3
		4	4	4	5	4	4	4	2	4	4	4	3	4	3	4	1
		5	2	5	5	5	5	5	3	5	3	5	1	5	1	5	2
		6	4	6	5	6	3	6	3	6	2	6	2	6	5	6	5
		7	4	7	4	7	3	7	1	7	1	7	2	7	2	7	2
		8	4	8	3			8	1	8	3	8	5	8	5	8	3
		9	3	9	5			9	1	9	2	9	1	9	5	9	3
		10	4	10	3			10	2	10	4	10	2			10	3
				11	2			11	4	11	3					11	4
				12	1			12	5	12	5					12	4
				13	2			13	4	13	3					13	5
				14	1			14	2	14	3					14	5
								15	2							15	2
								16	2							16	5
								17	3							17	3
								18	3								
								19	5								

3. MBMG should, with MDT's assistance, design forms and procedures for submission of new data and should develop procedures for additions and corrections to the database. Any available new landslide data from any source should be incorporated into the database to ensure that the database remains current. In this process, smaller landslides could also be incorporated with only minor modifications. The groundwork and basic procedures (appendix C) resulting from the current project could serve as a platform for any additional work.

4. MBMG does not expect that a lot of new landslide information will be developed from the MBMG mapping programs currently anticipated. Best projections at this time are that data from fewer than 20 District 2 landslides will become available for entry each year. In that context, MBMG agrees to maintain a landslide-database-maintenance file of new data at MBMG's expense through the end of State fiscal year 2007. At the end of that period, or sooner if an inordinate amount of information becomes available, MBMG and MDT will mutually decide whether an agreement for collating new information into the existing database, and revising the maps and pertinent text of this report, is warranted. If decided in the positive, a cooperative agreement will implement the work, utilizing a negotiated amount of MDT funds and MBMG matching services. Costs for the new work will reflect the amount of new data to be added, and the complexity of updating the maps and other interpretations.

12.0 DATA LIMITATIONS

Any use made of the data resulting from this project should consider the methods of collection and interpretation, and the scale at which the initial data were gathered:

- The original compilation of data was done at 1:250,000 scale; therefore, if the data are used at a larger scale, inaccuracies could occur in both location and shape.
- Locations were originally gathered using several methods: aerial-photo interpretation, literature references, aerial reconnaissance, and field mapping.
- Locations were checked by either fieldwork or aerial reconnaissance, but detailed mapping was not done in either case.
- Data have been provided by several investigators and at various scales, therefore inconsistency in definitions, recognition of types, and locations may exist. More detailed studies in specific areas may require corrections and/or additions to the database.
- The information, location, references, and definitions in the database and in this report are as complete as feasible at this time, but must be considered as products that will continue to evolve as new or improved data become available.
- The accuracy of the landslides located from aerial photographs varies according to date, quality, and scale of the photographs. Additional problems resulting from aerial-photographic interpretation include the following:
  - √ Landslides that are more recent than the aerial photography or fieldwork will not be shown.
  - √ Landslides that are smaller than approximately 500 feet (150 m) in the longest dimension may not be shown because they are too small to be clearly identified on the aerial photographs, and may be too small to be drawn on the 1:250,000-scale map.
  - √ Distinction is not always clear between terrace-shaped landslide deposits and alluvial terrace deposits in cases where they are both adjacent to streams.
  - √ Some landslide boundaries are less well defined than others: the upslope boundary is commonly better defined, often by the presence of a prominent scarp; but the toe or downslope boundary is usually not so well defined, so it is difficult to locate.
  - √ Delineation of boundaries between adjacent surficial deposits that grade laterally into or interfinger with one another may not be shown.
  - √ Stable masses of bedrock surrounded by landslide deposits, especially where only small knobs of the bedrock project through the landslide material, may not be recognized.

13.0 LITERATURE STUDY

During the course of this project, an extensive search for literature pertinent to landslides and geology of the Butte District was conducted. The resulting compilation (appendix F) is a set of bibliographies that identify literature within the categories of maps, texts, theses, newspaper articles, and general landslide literature.

14.0 CITED REFERENCES

Bailey, R.W., 1961, Madison River–Hebgen Lake earthquake and highway problems *in* Symposium on geology as applied to highway engineering, 12th Annual, 1961: Tennessee University, Engineering Experimental Station, Bulletin 24, p. 38–50.

Cruden, D.M. and Varnes, D.J., 1996, Chapter 3, Landslide types and processes, *in* Turner, A. K., and Schuster, R. L. S., *eds*., Landslides—Investigation and mitigation: Transportation Research Board, National Research Council, Special Report 247, National Academy Press, 673 p.

Curtiss, R.E., 1960, Geology of Hebgen dam site, Appendix *in* U.S. Corps of Engineers, Madison River, Montana, report on flood emergency, Madison River slide: U.S. Corps of Engineers, v. 2, Appendixes, p. II-1–II-3.

Curtiss, R.E., and Knight, D.K., 1960, Preliminary slide-stability studies, Appendix 9 *in* U.S. Corps of Engineers, Madison River, Montana, report on flood emergency, Madison River slide: U.S. Corps of Engineers v. 2, Appendixes, p. IX-1–IX-10.

McDonald, Catherine, 2001, Geologic and hydrogeologic investigation of the Clark Canyon landslide, Southwestern Montana: Montana Bureau of Mines and Geology Open-File Report MBMG 442, 35 p.

Wilde, E.M., and Bartholomew, M.J., 1986, Statewide inventory and hazard assessment of deep-seated landslides in Montana *in* Proceedings of the 37th annual highway geology symposium—Geotechnical aspects of Construction in mountainous terrain: Montana Department of Highways and Montana Division-Federal Highway Administration, p. 132–136.

APPENDIX A

COLOR PLATES

Figure 2. Location and outline of Montana Department of Transportation District 2 (Butte District) in southwestern Montana.

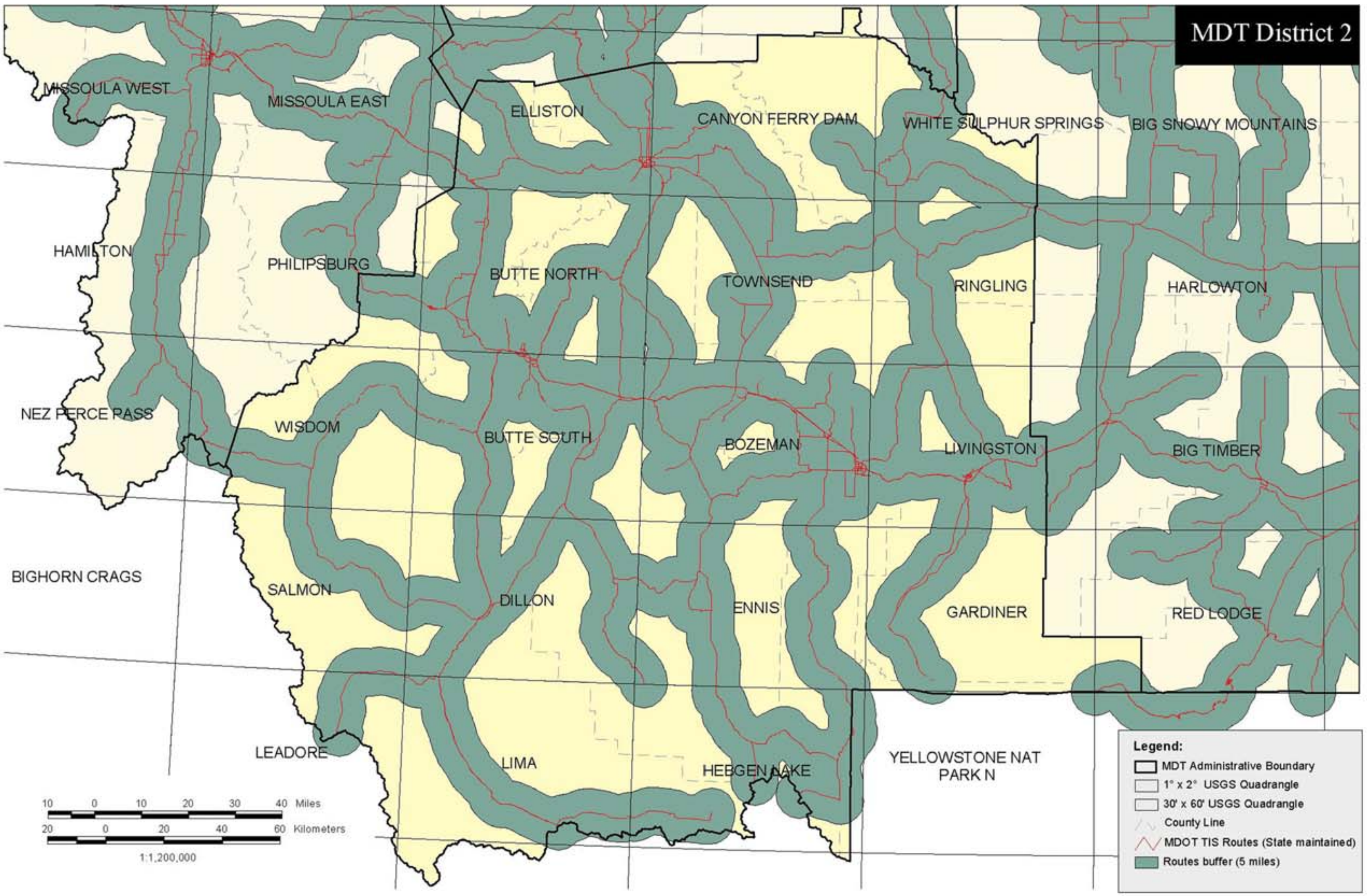


Figure 3. District 2 with 5-mile buffer zones. The 5-mile buffer zones cover a large-enough part of the total area to warrant a simplified inventory of all landslides, rather than those only along the roadways.

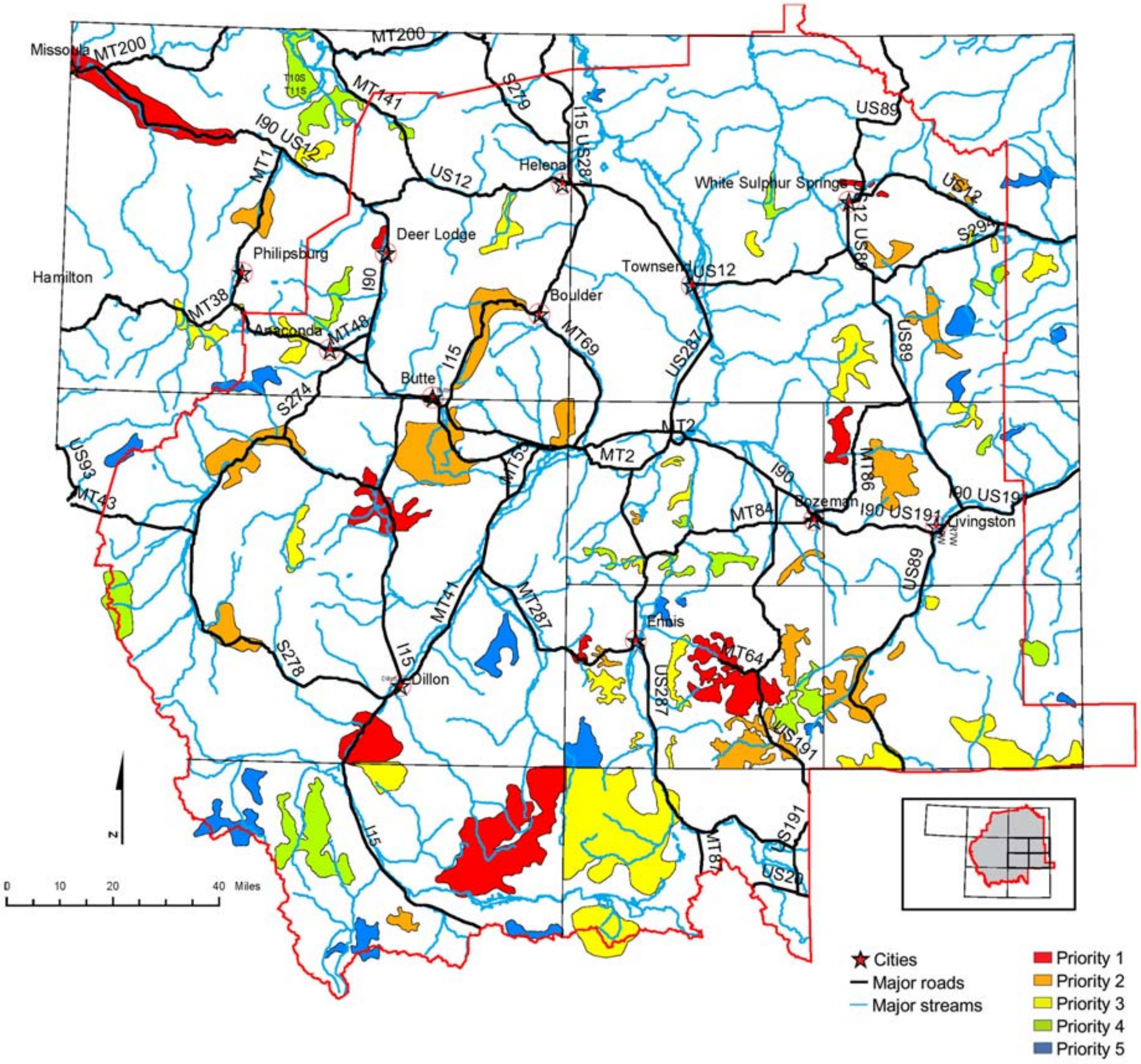


Figure 4. Priority areas for District 2. Areas most prone to landsliding were assigned priorities (1 being the highest) for probable further movement and possible damage.

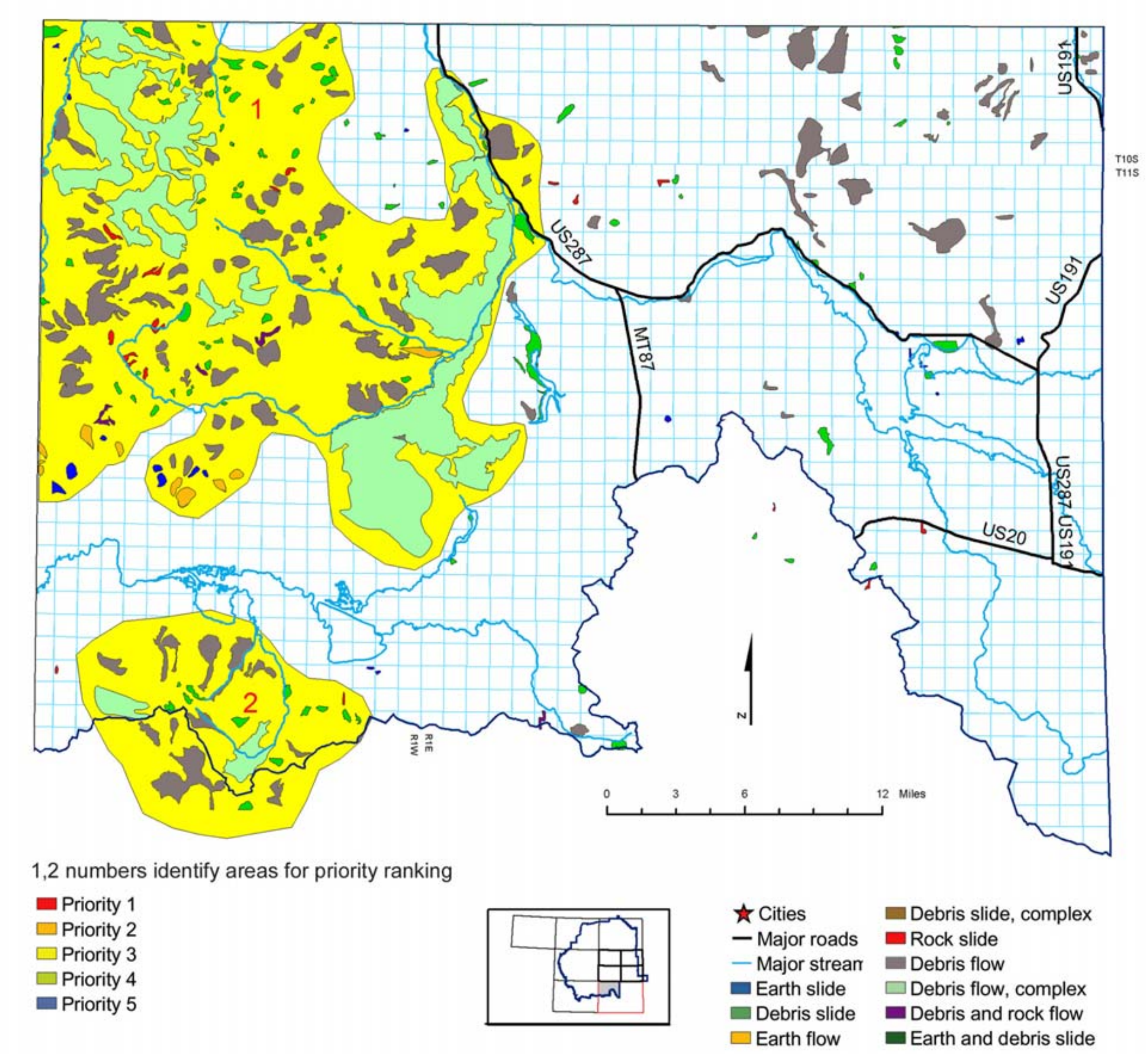


Figure 5. Clustered areas and priorities for the Ashton 1:250,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

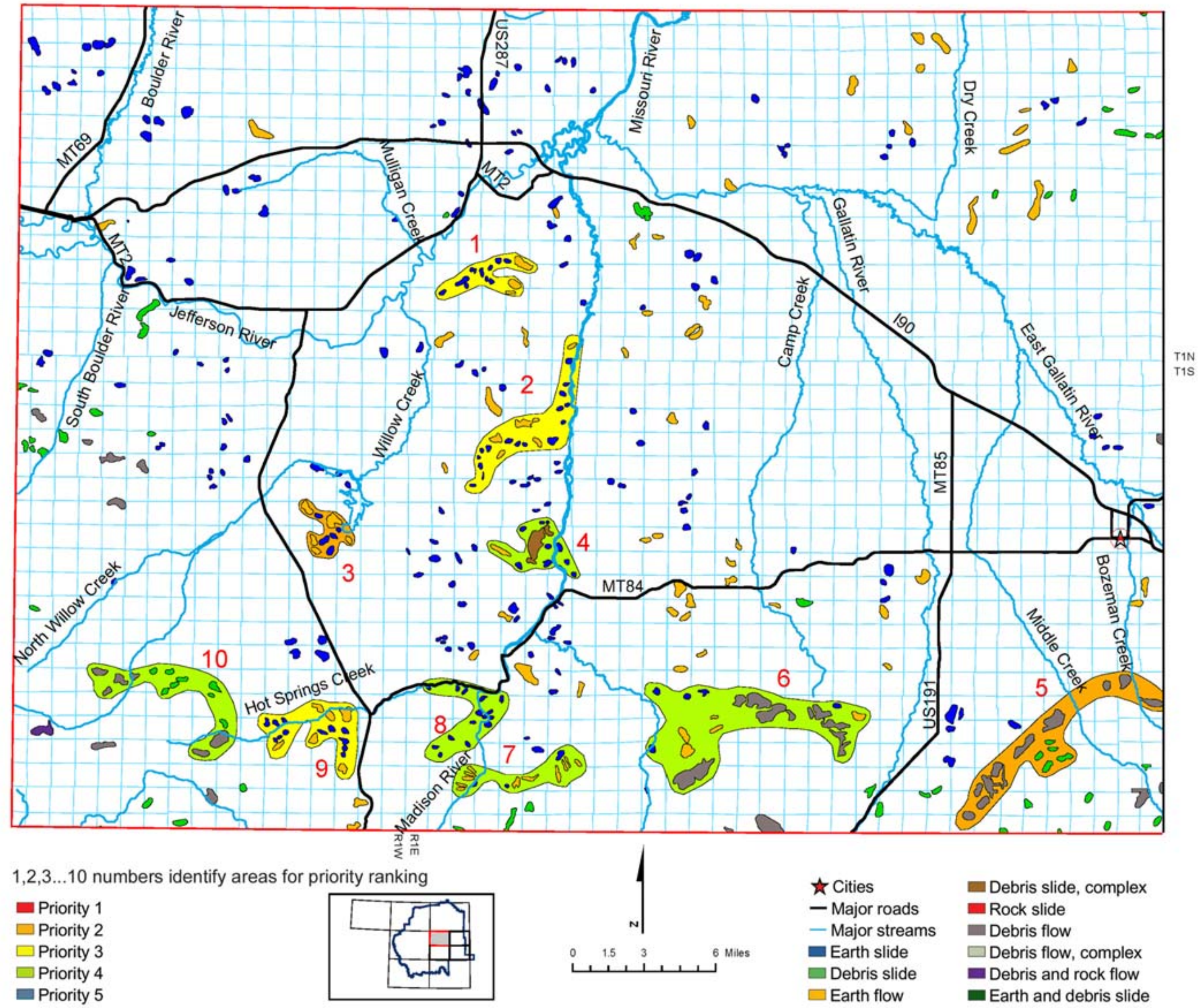


Figure 6. Clustered areas and priorities for the Bozeman 1:100,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

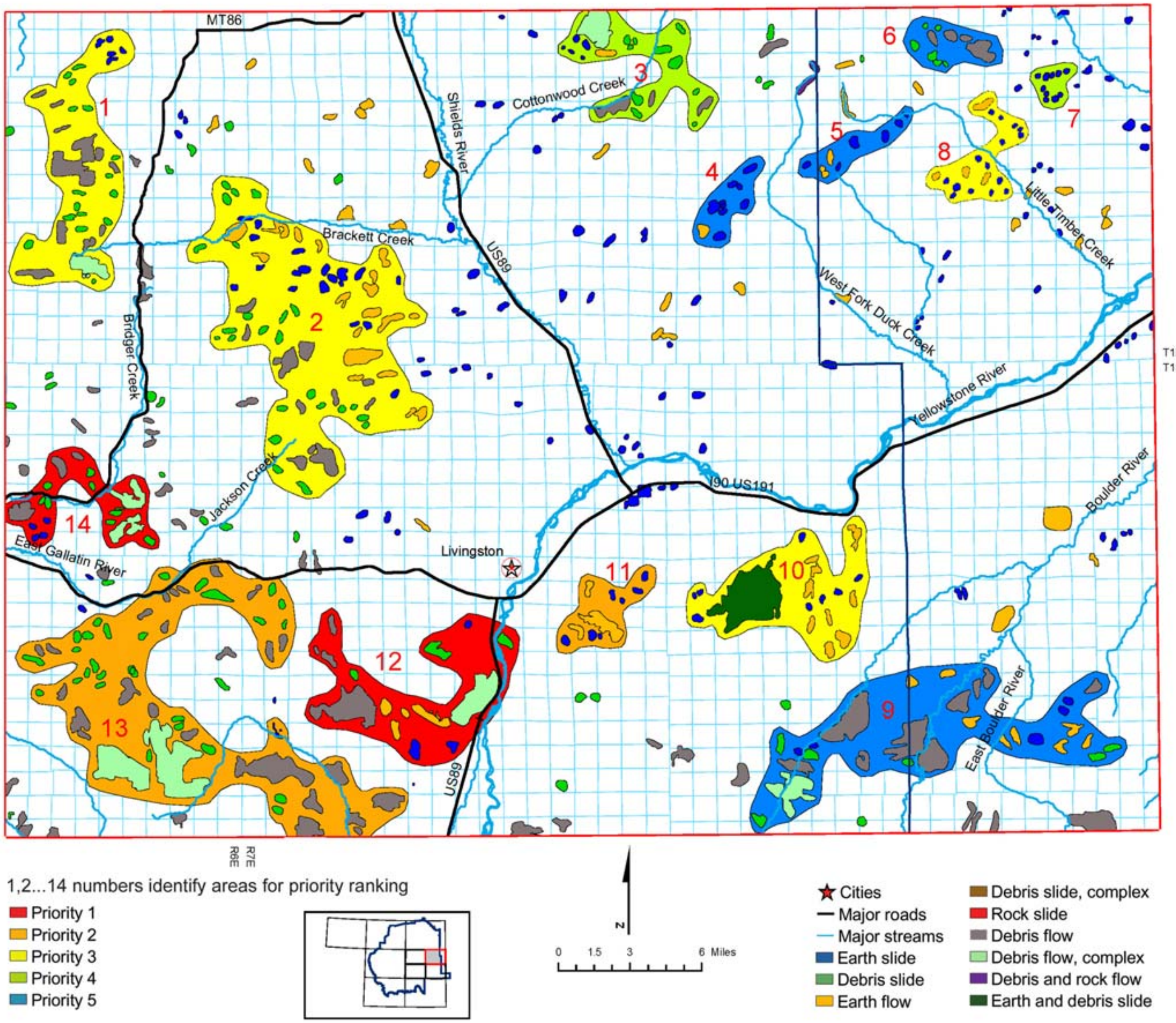


Figure 7. Clustered areas and priorities for the Livingston 1:100,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

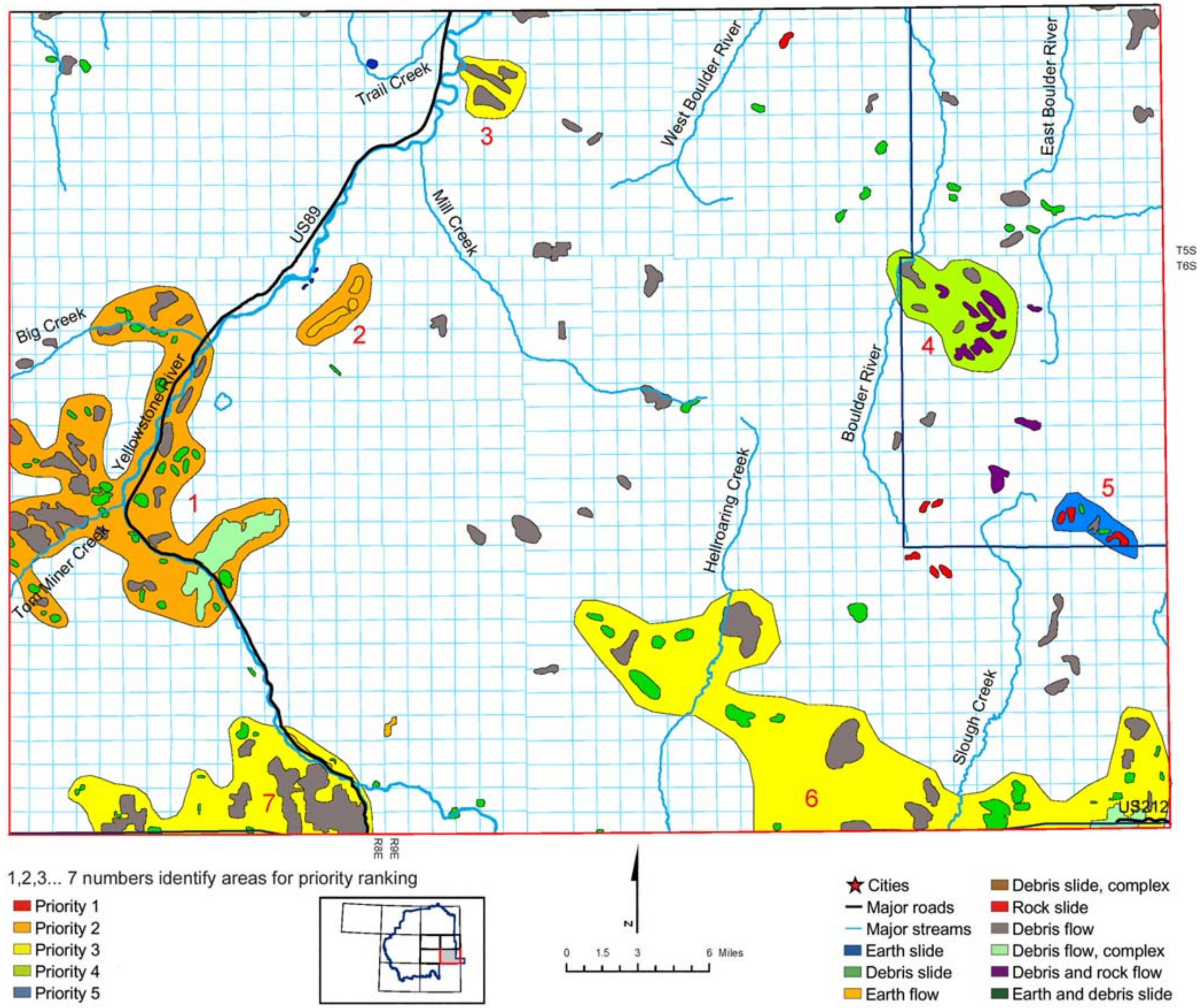


Figure 8. Clustered areas and priorities for the Gardiner 1:100,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

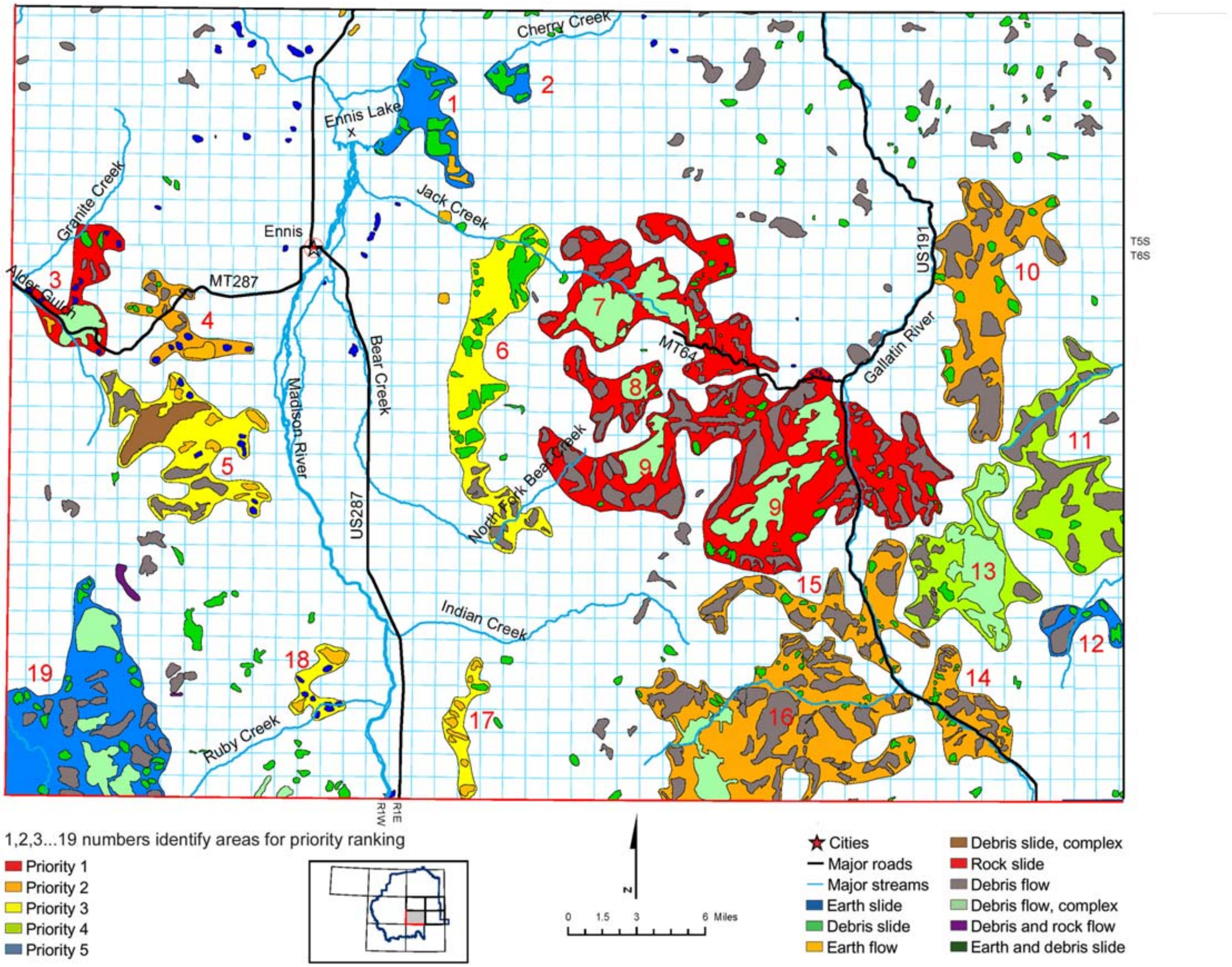


Figure 9. Clustered areas and priorities for the Ennis 1:100,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood for further movement and possible damage is prioritized by color (1–5, 1 is the highest).

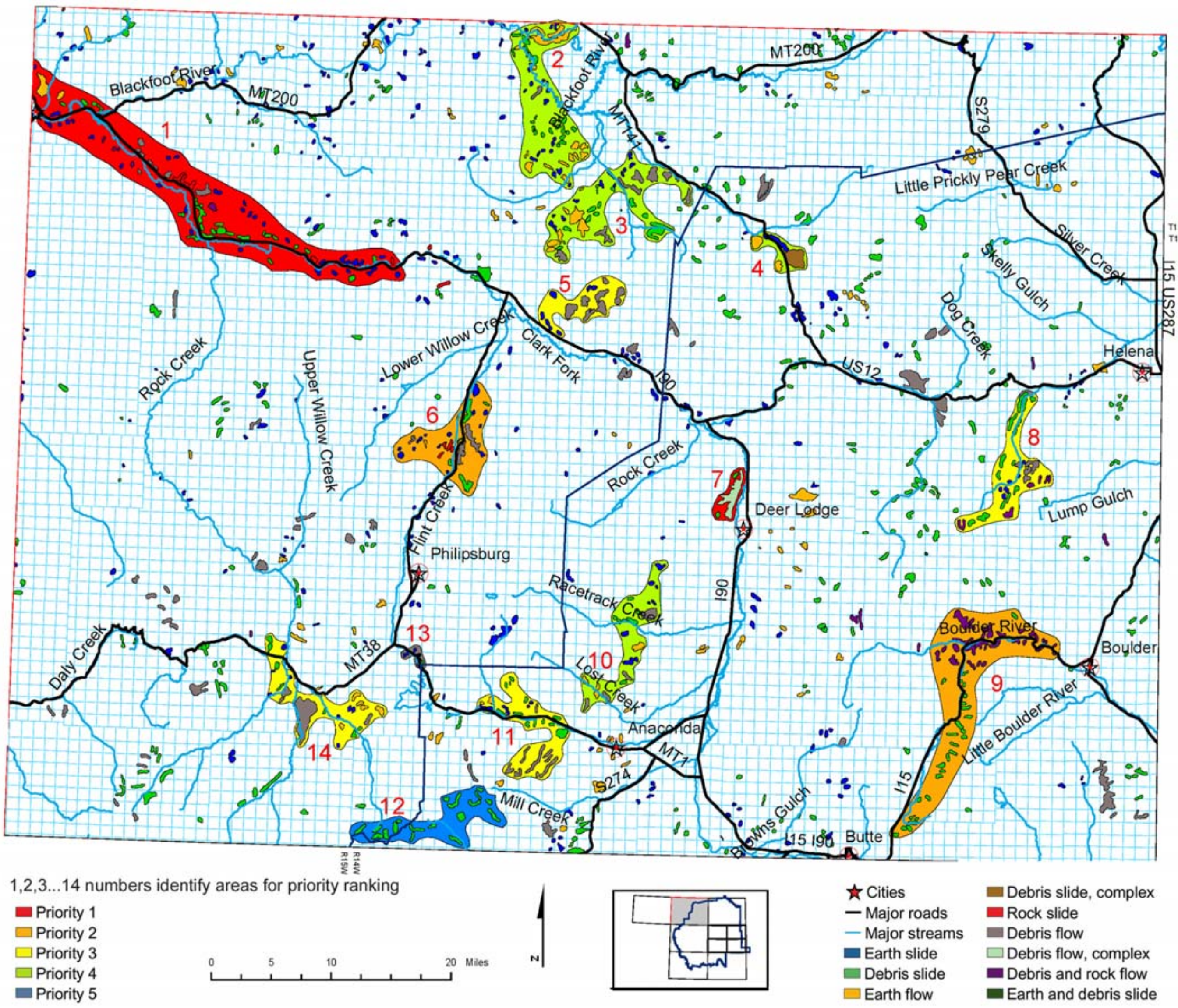


Figure 10. Clustered areas and priorities for the Butte 1:250,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

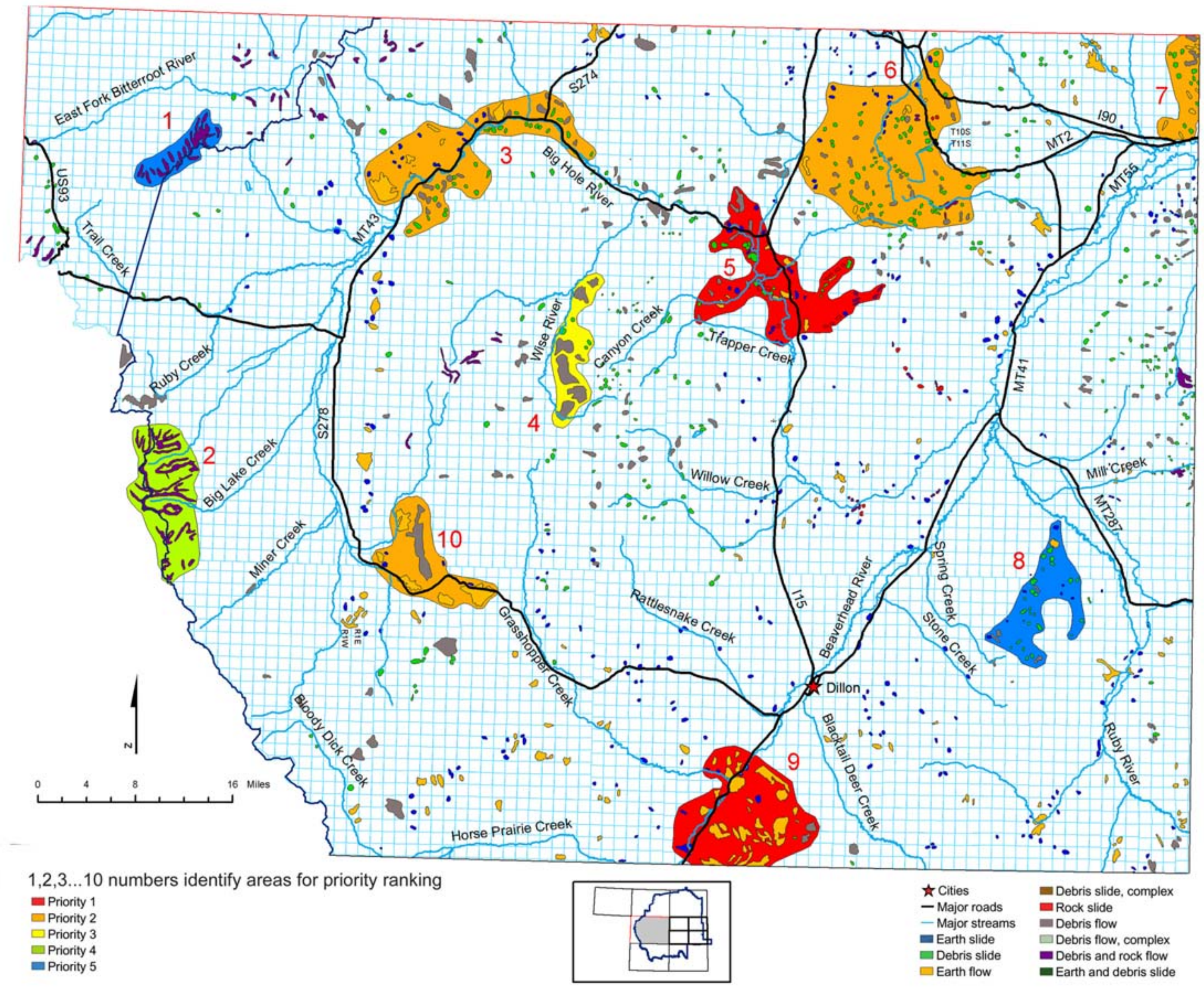


Figure 11. Clustered areas and priorities for the Dillon 1:250,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

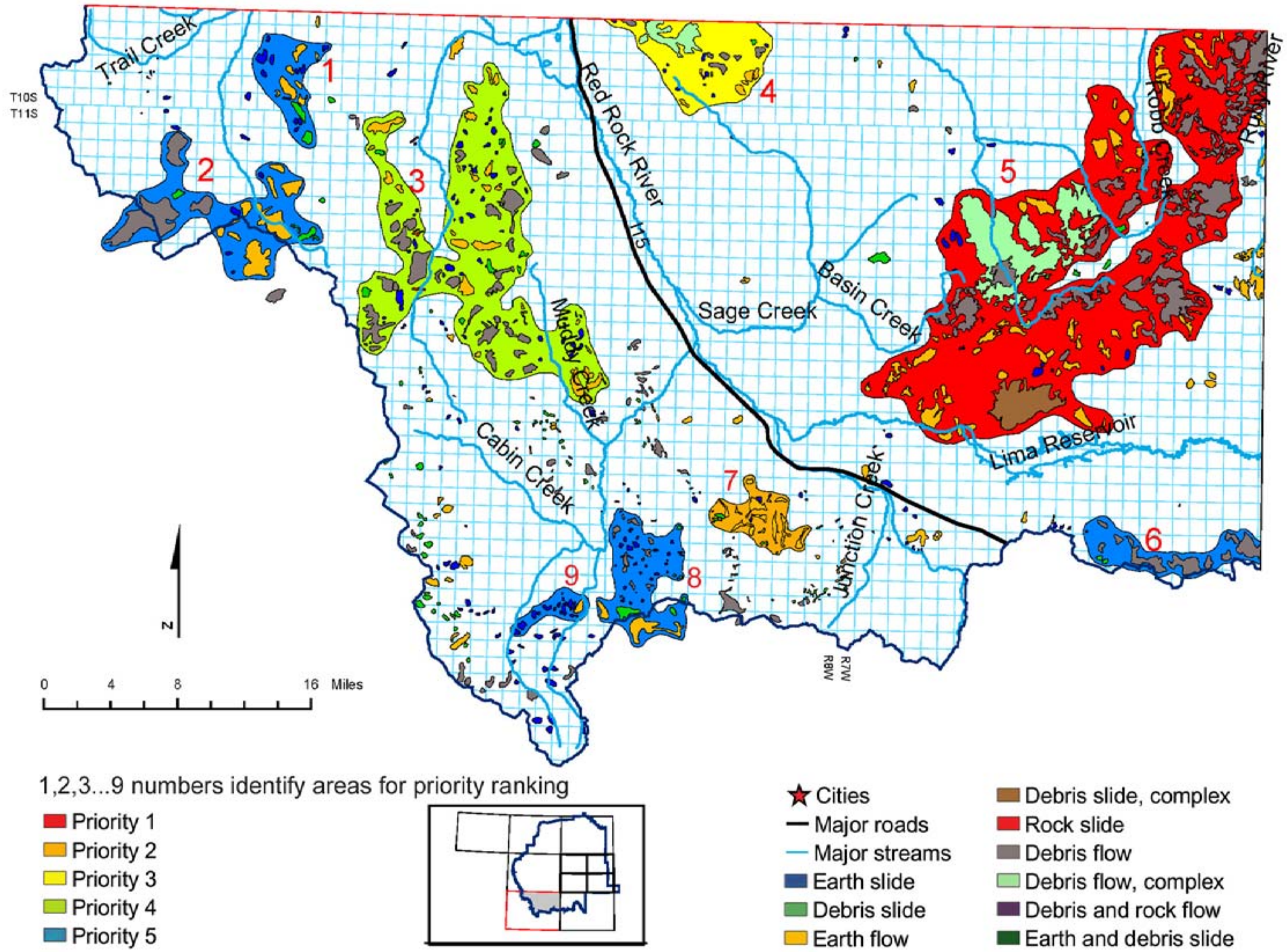


Figure 12. Clustered areas and priorities for the Dubois 1:250,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

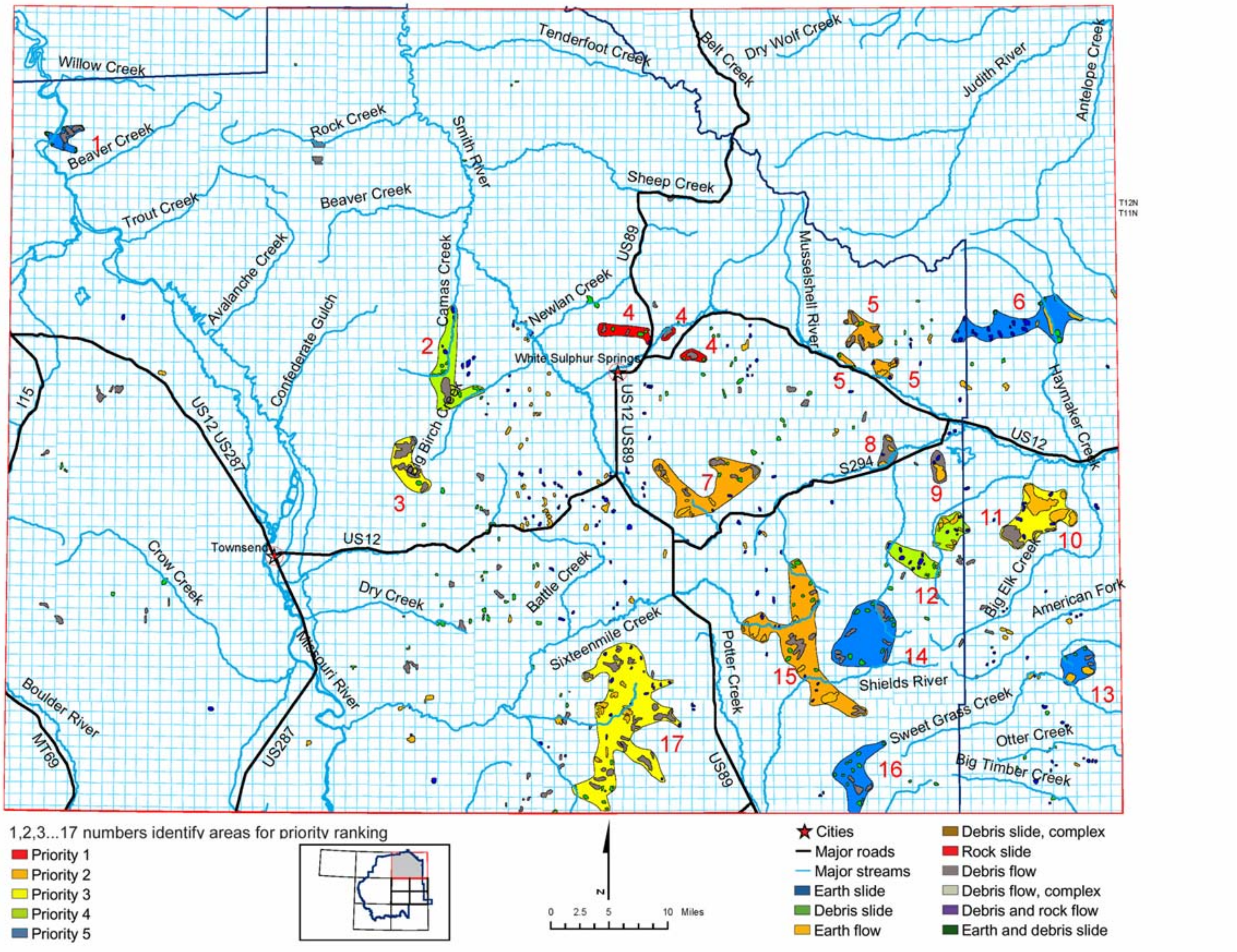


Figure 13. Clustered areas and priorities for the White Sulphur Springs 1:250,000-scale map area in District 2. Landslide-cluster areas are identified numerically for the *Geologic Discussion* and table 14; likelihood of further movement and possible damage is prioritized by color (1–5, 1 is the highest).

APPENDIX B

GENERALIZED DESCRIPTIONS OF ORIGINATING FORMATIONS

B.1.0 QUATERNARY FORMATIONS

B.1.1 Qu—Quaternary undifferentiated units

Recent alluvial, colluvial, terrace, talus and pediment deposits. Composed of unconsolidated silt, sand, gravel or rocks commonly located along valley bottoms and valley sides. Unconsolidated nature of the material allows movement to occur on over-steepened slopes and where undercutting occurs either naturally or by human activities. Included deposits are as follows:

Qa—Avalanche deposits or alluvium
Qaf—Alluvial fan deposits
Qal—Alluvial deposits of modern stream channels and flood plains
Qat—Alluvial terraces
Qc—Colluvial deposits
Qgr—Gravel deposits
Qs—Undivided sedimentary deposits
Qta—Talus deposits
Qtp—Pediment gravel deposits
QTgr—Gravel deposits

B.1.2 Qglu—Quaternary undifferentiated glacial units

Unconsolidated glacial materials that mantle the older rocks or formations. Till and moraine deposits are composed of unsorted clay, sand and pebbles in contrast to poorly to well-sorted clay, silt, sand and gravel in outwash deposits. Lake sediments consist of clay, silt and sand deposited in standing water. Unconsolidated nature of the material, the presence of clay and silt, as well as the presence of water in many of these deposits contribute to the potential for movement. Any undercutting, additional moisture and over-steepening of slopes often causes movement. Deposits included are as follows:

Qgl—Glacial lake deposits and reworked glacial lake deposits
Qgm—Glacial Moraine deposits
Qgt—Glacial till deposits
Qm—Glacial moraine
Qmc—Glacial moraine and colluvial deposits
Qo—Glacial outwash deposits

B.1.3 Qvu—Quaternary undifferentiated volcanic units

Volcanic tuff and ash-flow deposits that may be consolidated or unconsolidated. Contains ash, clay and silt that contribute to the potential for movement. Undercutting, added moisture and over-steepening of slopes often contributes to the potential for landsliding, whether natural or human in origin. Deposits included are as follows:

Qyh —Huckleberry Ridge tuff deposits found near Yellowstone Park

B.2.0 TERTIARY FORMATIONS

B.2.1 Tsu—Tertiary undifferentiated, predominantly sedimentary formations

Generally unconsolidated to poorly consolidated deposits of sedimentary origin. These clastic sediments are often located in intermontane valleys and are composed of gravel, sand, silt, clay, and coal. Also includes some igneous materials and swelling clays (bentonitic). Undercutting, added moisture and over-steepening of slopes in these deposits often contributes to the potential for landsliding, whether natural or human in origin. Coal beds often contain water and may be aquifers. Addition of water to swelling clays and to some coals not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

Tbz—Undivided Bozeman Group and related valley-fill deposits
Tca—Climbing Arrow Formation
Tdc—Dunbar Creek Formation
Tftr—Tongue River Member of the Fort Union Formation
Tmva—Undivided Madison Valley formation (informal)
Ts—Undivided sediment or sedimentary rocks, or basaltic rocks near Sweetwater Creek
Tsc—Sixmile Creek Formation
Tse—Sepulcher Formation
Tslc—Lost Creek Tuff Member of the Sepulcher Formation
Ttr—Travertine; lake or hot-springs deposits
Tw—Wasatch Formation
TKb—Undivided Beaverhead Group
Tkfu—Undivided Fort Union Formation

B.2.2 Tvu—Tertiary undifferentiated volcanic formations

Igneous extrusive flows and pyroclastic deposits. Composed mainly of andesite, rhyolite and basalt with swelling (bentonitic) ash and tuffs included. Undercutting, added moisture and over-steepening of slopes often contributes to the potential for landsliding, whether natural or human in origin. Addition of water to swelling clays not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

Ta—Andesitic rocks
Tab—Andesitic and basaltic rocks
Tae—Hyalite Peak volcanics, andesite epiclastics
Tanf—Hyalite Peak volcanics, andesite flows
Tba—Undivided basaltic rocks
Tc—Challis volcanic rocks
Tcv—Challis Volcanic deposits
Tgcf—Golmeyer Creek volcanics, andesite flows
Tlc—Lowland Creek volcanic rocks
Tmlv—Medicine Lodge volcanic rocks
Trv—Rhyolitic volcanic rocks
Trvp—Rhyolitic pyroclastic rocks of the Dillon volcanics

Tv—Undivided volcanic rocks
Tvt—Undivided felsic tuff
Tvu—Undivided volcanic rocks

B.2.3 Tpu—Tertiary undifferentiated plutonic formations

Igneous extrusive plutons composed of granitic rocks, primarily quartz monzonite, diorite, and syenite. The plutons (including large bodies called batholiths) are present in most mountain ranges and are frequently mineralized. These formations are generally well consolidated. Over-steepening, undercutting and faulting are generally the factors that contribute to movements in these deposits. Formations included are as follows:

Tbmg—Undivided biotite-muscovite granodioritic rocks
Tdi—Dacite, intrusive body
Tdp—Dacite porphyry
Tg—Granite deposits
Tgd—Undivided granodioritic rocks
Ti—Undivided intrusive rocks
TKg—Undivided biotite-muscovite granitic rocks
TKgd—Undivided hornblende-biotite granodioritic rocks

B.3.0 CRETACEOUS FORMATIONS

B.3.1 Ksh—Undifferentiated Cretaceous formations composed primarily of shales

Unconsolidated to consolidated shales, clays, silts and very-fine-grained sands. Shales and clays are often bentonitic (swelling). May contain members or lenses composed of sandstones or silts. Over-steepening, undercutting and faulting are generally the factors that contribute to movements in these deposits. Addition of water to swelling clays not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

Kb—Bearpaw Formation
Kbc—Billman Creek Formation
Kc—Carlile Formation
Kcl—Claggett Formation
Kco—Cody Formation
Kcus—Upper Shale Member of the Cody Shale Formation
Kd— Dunkelberg Formation
Kk—Kootenai Formation
Klf—Undivided Landslide Creek through Frontier Formations
Km—Undivided sedimentary rocks of McCartney Mountain
Kmfr—Undivided Mowry through Fall River Formations
Kmi—Miners Creek Formation
Kmt—Undivided Mowry and Thermopolis Formations
Ks—Undivided sedimentary rocks
Kt —Thermopolis Formation
Ktc—Telegraph Creek Formation

B.3.2 Kss—Undifferentiated Cretaceous formations composed primarily of sandstones

Unconsolidated to consolidated clays, silts and very-fine to medium-grained sands. May contain members or lenses composed of shales and clays that may be swelling. Over-steepening, undercutting and faulting are generally the factors that contribute to movements in these deposits. Addition of water to swelling clays not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

Kblq—Little Sheep Quartzite of the Beaverhead Group
Kbm—Monida Sandstone of the Beaverhead Group
Kcs—(Elkridge Creek Member of the Cody Shale formation
Ke—Eagle Formation
Ketc—undivided Eagle and Telegraph Creek Formations
Kev—Virgelle Member of the Eagle Formation
Kf—Frontier Formation
Khfh—Undivided Hell Creek and Fox Hills Formations
Khov—Hoppers Formation
Kjr—Judith River Formation
Kjre —undivided Judith River through Eagle Formations
Kse—Sedan Formation

B.3.3 Kvu—Undifferentiated Cretaceous volcanic formations

Igneous extrusive flows and pyroclastic deposits. Composed mainly of andesite, rhyolite and basalt with swelling (bentonitic) ash and tuffs included. Undercutting, added moisture and over-steepening of slopes often contributes to the potential for landsliding, whether natural or human in origin. Addition of water to swelling clays not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

Kem—Undivided Elkhorn Mountain volcanic deposits
Klsr—Volcanic deposits of the Sliderock Mountain Member of the Livingston Group

B.3.4 Kpu—Undifferentiated Cretaceous plutonic rocks

Igneous extrusive plutons composed of granitic rocks: primarily aplite, alaskite, pegmatite, granite, diorite, monzonite and other related felsic rocks. The plutons (including large bodies called batholiths) are present in most mountain ranges and are frequently mineralized. These formations are generally well consolidated. Over-steepening, undercutting and faulting are generally the factors that contribute to movements in these deposits. Formations included are as follows:

Ka—Aplitic rocks
Kal—Alaskite, aplite, pegmatite, and related felsic rocks
Kbgg—Undivided biotite granodioritic and granitic rocks
Kg—Granitic rocks
Kgd—Granodioritic rocks
Ki—Undivided intrusive deposits
Kit—Undivided intrusive rocks of the Tobacco Root Batholith

Kmd—Monzodioritic rocks
Kmg—Undivided monzogranitic rocks (Montana Group)

B.4.0 JURASSIC FORMATIONS

B.4.1 Ju/TRu—Undifferentiated Jurassic, Triassic and Mississippian formations

Composed of well-consolidated to poorly-consolidated coals, shales, claystones, siltstones, and sandstones. Includes varying amounts of swelling clays and ashes. Undercutting, added moisture and over-steepening of slopes in these deposits often contributes to the potential for landsliding, whether natural or human in origin. Coals often contain water and may be aquifers. Addition of water to swelling clays and some coals not only contributes to movement potential but causes problems when roads or other types of construction are located on or near these deposits. Formations included are as follows:

KJme Undivided Morrison Formation and Ellis Group
KJs—Undivided sedimentary rocks
Jm—Undivided Morrison Formation
Ju—Undivided Jurassic age rocks
TRu—Undivided rocks of Triassic age

B.5.0 PALEOZOIC FORMATIONS

B.5.1 Pu—Undifferentiated Paleozoic (Permian, Pennsylvanian, Mississippian, Devonian, Ordovician and Cambrian) formations

Composed of generally well-consolidated coals, shales, claystones, siltstones, sandstones and related rocks of sedimentary origin. Includes formations composed primarily of quartz and limestone. In these deposits jointing, bedding orientation, faulting and, whether natural or human in origin, undercutting, added moisture, and over-steepening of slopes often contributes to the potential for landsliding. Formations included are as follows:

Pp—Undivided Phosphoria Formation
Ppq—Undivided Phosphoria and Quadrant Formations
Ps—Undivided sedimentary deposits
Pu—Undivided rocks
PDs—Undivided sedimentary rocks
PPq—Quadrant Formation
PPMab—Undivided Amsden and Big Snowy Formations
PPMpa—Undivided Phosphoria and Quadrant Formations and Amsden Group
Ml—Lodgepole Formation
Mm—Undivided Madison Group
Mmd—Middle Canyon Formation
MDtj—Undivided Three Forks and Jefferson Formations
MDtjm—Undivided Three Forks Formation, Jefferson Formation and Madison Group
MDuv—Undivided Mississippian through Devonian-age rocks

DOt—Undivided Three Forks, Jefferson, and Big Horn Formations
Ocsp—Undivided Snowy Range and Pilgrim Formations
Cf—Flathead Formation
Cm—Meagher Formation
Cmf—Undivided Meagher Limestone
Cp—Park Shale Formation
Cpf—Undivided Park, Meagher, Wolsey and Flathead Formations
Cpl—Pilgrim Limestone
Cs—Undivided sedimentary rocks
Cu—Undivided Cambrian age rocks

B.6.0 PROTEROZOIC FORMATIONS

B.6.1 pCbu—Undifferentiated Late Proterozoic formations

Composed primarily of slightly to moderately metamorphosed rocks, including quartzites, carbonates and other related rocks of the Precambrian Belt Supergroup. In these units, jointing, adverse bedding orientation, steeply dipping beds, faulting undercutting, and over-steepening of slopes often contributes to the potential for landsliding. Formations included are as follows:

pCb—Undivided basaltic rocks
pCm—Undivided mafic intrusive rocks
Ybo—Bonner quartzite
Yc—Undivided carbonate deposits of the middle Belt Supergroup (informal)
Ygr—Garnet Range Formation
Yhe—Undivided Helena and Empire Formations
Yl—Undivided Lemhi Group
Ym—Undivided Missoula Group (McNamara Formation)
Ymb—Undivided metamorphosed rocks of the Belt Supergroup
Ymm—Undivided metamorphosed Missoula Group or foliated metasedimentary rocks, probably part of the Bonner Group
Yms—Mount Shields Formation
Ynl—Undivided Newland and Lahood Formations
Ypi—Pilcher quartzite
Yq—Undivided quartzite of the Belt Supergroup or Grace Lake
Ysg—Undivided Spokane and Greyson Formations
Ysn—Snowslip Formation
Yss—Undivided Snowslip and Shephard Formations
Yy—Undivided Yellowjacket Formation
Xi—Undivided mylonitic orthogneiss and granitic sills (intrusives)

B.7.0 ARCHEAN FORMATIONS

B.7.1 pCAu—Undifferentiated early Proterozoic and Archean formations

Primarily highly metamorphosed rocks. Includes gneiss, amphibolite, granite, marble, quartzite, and mylonitic rocks. May include some mineralization. In these deposits jointing, adverse bedding orientation, steeply dipping beds, faulting, undercutting, and over-steepening of slopes often contributes to the potential for landsliding. Formations included are as follows:

XAb—Undivided biotite gneissic rocks
Aam—Amphibolite
Aamh—Amphibolite and hornblende gneiss
Aga—Amphibolite and gneissic rocks
Agn—Gneissic rocks
Agp—Granitic porphyry of the Hellroaring Creek
Am—Undivided marble
Ama—Undivided marble and amphibolite
Aq—Undivided quartzite
Aqfg—Quartzofeldspathic gneiss
Aqbg—Quartzofeldspathic biotite gneiss
As—Biotite schist
At—Undivided mylonite of the Crooked Creek shear

APPENDIX C

GIS METHODOLOGY AND INSTRUCTIONS FOR DATABASE USE

C.0 GIS METHODOLOGY

C.1.1 Data Capture

GIS landslide coverages were constructed in Arc/Info 7.2.1, and then converted into ArcView 3.2 shapefiles; a structure was developed that can be used with ArcView for presentation of the data. Entry of landslide data into the database was planned to eliminate redundant locations. Initial GIS efforts were focused on digitally capturing all available landslide data from both MBMG and at MDT. The locations of the landslides from the literature were captured in the 1985–1986 MBMG digital landslide database, but only as points representing the centers of the movement. In addition, the landslide shapes from recent MBMG mapping were selected from digital coverages and added to the landslide coverage. Labels were added and the resulting polygons were coded by map number.

A structure for the database was developed based on the types of data available, the classification system agreed upon, and other items of concern to MDT and MBMG. Once the structure was developed, a set of written procedures was created to assist the user, and the information from all available sources was entered into the database.

Once the data capture was complete, the GIS readily permitted display of all landslide locations, or selected landslides as determined by categories in the database. Additional layers can be added for purposes of risk analysis; for example, topography is readily available, and digital geologic data are available at either the 1:100,000 or 1:250,000 scales over most of MDT District 2.

C.1.2 Compilation of Landslide Locations

The first step in the creation of the landslide coverage was to scan each of the 1:250,000-scale quadrangle maps on which landslide outlines had been compiled (Ashton, Bozeman, Butte, Dillon, Dubois, and White Sulphur Springs), and the outline of MDT's District 2. Data available from MDT included landslides located along specified routes. For MBMG's data, each quadrangle is covered by as many as four paper map sheets displaying landslide locations; the locations obtained by stereoscopic interpretation of aerial photographs, by aerial-reconnaissance mapping, or by field work are plotted on from 1 to 3 maps for each 1:250,000-scale quadrangle. One additional map for each quadrangle has landslide locations plotted from literature references.

After scanning, the resulting images were then geo-referenced to known coordinates within specified tolerances, and then geo-rectified. The resulting landslide images were registered to the boundary coverage. RMS (root mean square, a deviation measurement) values were kept within accepted standards for the scale (1:250,000). The resulting scanned images were then converted to a grid. The grid was then traced using both a custom macro in ArcEdit and concurrent digitizing. At this point each location from the source maps should correspond to a point in the MBMG digital database.

However, this process created some overlapping polygons, or redundant locations, when the same landslide was plotted from more than one source map. This problem included areas where recent mapping and previously published data covered the same general location, or the landslide was located by more than one method (air-photo interpretation, aerial-reconnaissance mapping or field mapping), and so appeared on more than one source map. Therefore, once the initial capture was complete, outlines from the various source maps (now a Geographic Information System (GIS) polygon coverage) were plotted as paper maps and examined. This resulted in the need for extensive editing to obtain the final shapes kept in this study, but ensured that all available data were included.

Where problems were readily solved, GIS personnel made those changes in the polygon coverage. The project geologist then made the final outline determination for the remaining areas of overlap, and the necessary changes were made to the polygon coverage by GIS personnel. The corrections completed during this process were done using the ArcEdit module.

C.1.3 Database Structure

The database accompanying the shape files was tailored to meet the needs of MDT and the general public. An example of a page as it appears in the database is given in table 15. The database structure will be included in the GIS metadata. This structure is a function of the landslide classification scheme developed for the study, as well as discussions between MDT and MBMG personnel concerning what information should be included in the structure.

Part of the database structure was developed concurrently with creation of the location shape-files. Each landslide location was coded as a polygon and assigned a unique number in the new database. If any polygon coded for this new database corresponded to a location from the 1985–1986 MBMG database or a MDT location, the old point was evaluated to see if it was unique. If it was not, entries were included in the new database to cross-reference the new polygon number/location to the old MDT or MBMG data source number (columns labeled Biblio # and 1985–1986 ID from table 15). If the polygon location was unique, the number assigned in the new database became the only identifier.

Table 15. Example of information as it appears in the database for the Butte District. Explanation of "type" is provided in the metadata file.

Area in Square Meters	Perimeter in Meters	ID Number	Latitude	Longitude	Northings	Eastings	Map	Biblio #	Source	Type	1985–1986 ID	Area in Acres
157,409.938	1,442.161	2,041	45.613832	-113.034599	157,790.7464	324,479.6192	dil2		aphoto	2		38
207,264.375	1,761.544	2,042	45.635883	-112.112388	157,418.4342	396,415.8755	dil2		aphoto	2		51
134,979.906	1,626.349	2,043	45.625531	-112.515118	157,396.5439	365,001.2225	dil2		aphoto	7		33
1,404,679.500	8,804.337	2,044	45.599648	-113.228173	156,916.0375	309,326.6980	dil1		arecon	7		347
12,982,284.000	20,791.162	2,045	45.642450	-110.353096	155,114.8021	533,514.9665	boz3		aphoto	1/3		3,206
424,030.313	2,365.334	2,046	45.599134	-113.369183	157,392.1900	298,338.6164	dil2		aphoto	2		104
391,902.938	2,383.301	2,047	45.633168	-112.187848	157,315.9239	390,527.1812	dil2		grecon	2		96
580,631.250	3,085.445	2,048	45.648044	-111.421150	157,210.2009	450,304.6734	boz3		aphoto	3		143
268,892.906	1,953.373	2,049	45.658025	-110.862394	157,406.3089	493,856.7055	boz3		aphoto	2		66
116,247.398	1,402.447	2,050	45.657711	-110.927270	157,461.5112	488,802.1822	boz3		aphoto	1		28
138,915.469	1,372.957	2,051	45.652708	-111.245019	157,407.0073	464,037.8917	boz3		aphoto	1		34
384,030.531	3,013.858	2,052	45.659854	-110.296592	157,001.9789	537,938.0183	boz2	67	lit	3	811	94
423,884.594	3,157.040	2,053	45.650806	-111.017393	156,826.4458	481,766.7711	boz3		aphoto	3		104
449,430.719	2,744.906	2,054	45.652911	-110.830208	156,795.1104	496,354.4544	boz3		aphoto	2		111
236,558.250	2,020.881	2,055	45.654211	-110.911292	157,050.1679	490,039.8661	boz3		aphoto	2		58
246,866.375	1,848.707	2,056	45.656914	-110.445619	156,804.4894	526,323.9666	boz3		aphoto	1		60
1,411,787.125	6,414.892	2,057	45.597652	-113.141703	156,377.3513	316,053.2679	dil2		aphoto	6		348
117,472.414	1,415.357	2,058	45.643174	-111.534272	156,891.7665	441,478.1285	boz3		aphoto	1		29
518,738.313	3,184.163	2,059	45.623421	-112.346822	156,671.3575	378,103.8076	dil1		grecon	3		128
177,451.984	1,768.124	2,060	45.632723	-111.983262	156,740.1935	406,464.1026	boz3		aphoto	2		43
6,044,030.500	11,684.902	2,061	45.584366	-113.071891	154,652.0736	321,425.4520	stmap			6		1,493

Descriptive information was added to the project polygon attribute table and assigned a code. The attributes include bibliography number, source, author of literature references, type, movement year, and ID number (table 15). Each polygon was then coded according to the attributes/information available for it. In addition, a polygon attribute called "acres" was created and calculated based on the formula: acres = area (square meters)/4048.33 for each landslide polygon. (last column in table 15).

The database can be queried for any attribute included in the database. An example query and general instructions for use of the database in ArcView are given below.

C.2 Instructions for Use of Database

Using the ESRI ArcView software, version 3.2, the user can see the spatial data and make selections in the current view (screen image) or select records in the shape file attribute table. After an item is selected it will then be highlighted.

To select records with certain characteristics the user can use the Query Builder Tool to construct an SQL (Structured Query Language) statement. The user can then select from all records, select from, or add to previously selected records.

The first step in performing these types of operations is to open ArcView. The user will then see the following prompt: "Open with a new view." Click on OK (figure 14).

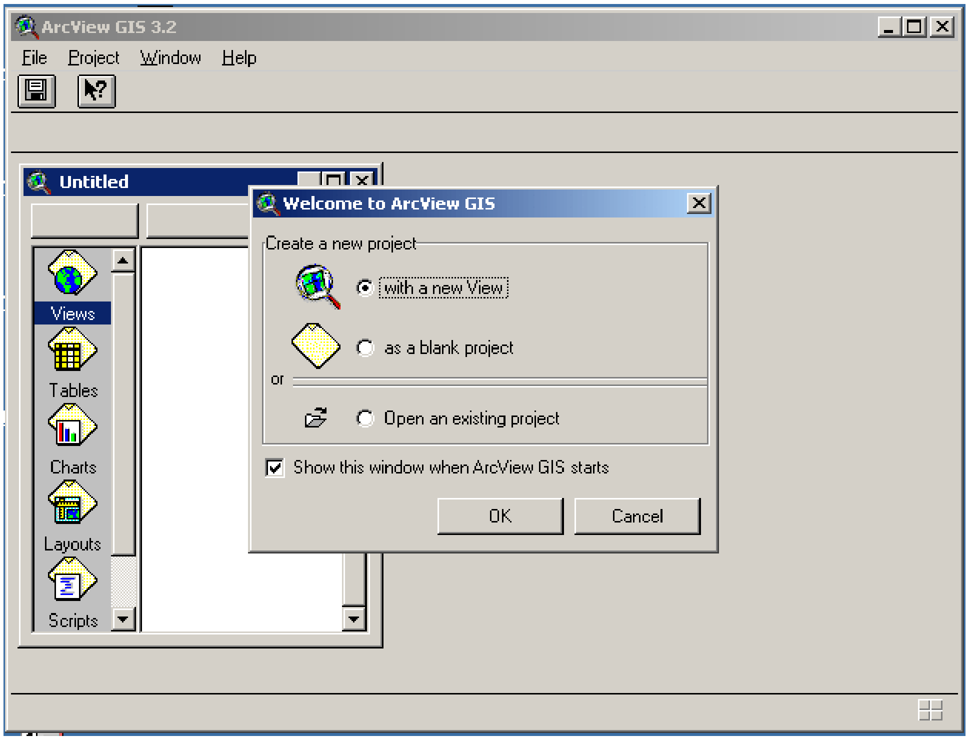
C.3 General Editing Procedures

The user will then see the prompt: "add data." Again, click on OK. This will bring up a pop-up menu, that can be used to navigate to the Dist2_poly.shp file. Click on that file and then click on open. Click to put a check in the box in front of the file name on the left side of the view. This will draw the shape file to the view.

Next, click directly on the name of the file to the left of the view. This creates a raised border around the name.

At the top of the ArcView window is a row of drop down menus; below are 2 rows of buttons (figure 15). By choosing "Start editing" from the **Theme** drop-down menu, you can draw new polygons or edit the vertices of existing polygons. The 3rd (Vertex Edit) and 13th (Drawing Tool) buttons on the bottom row have the drawing tools to do this type of spatial editing. When you are done editing, click on "Stop editing" in the **Theme** drop-down menu and save edits at the prompt.

Clicking on the 5th (Open Theme Table) button from the left in the first row will bring up the attribute table for the polygon shape files. It also changes to the table-editing window.



Create a new project

● with a new View

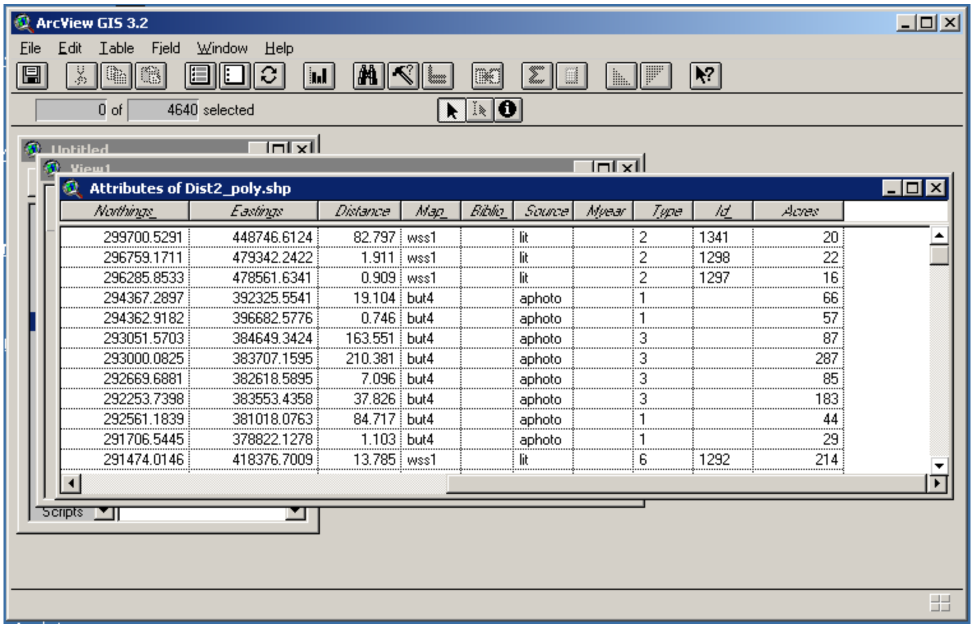
○ as a blank project

or

○ Open an existing project

☑ Show this window when ArcView GIS starts

Figure 14. Starting screen illustrations in database.



0 of 4640 selected

Northings_	Eastings	Distance	Map_	Biblio_	Source	Myear	Type	Id_	Acres
299700.5291	448746.6124	82.797	wss1		lit		2	1341	20
296759.1711	479342.2422	1.911	wss1		lit		2	1298	22
296285.8533	478561.6341	0.909	wss1		lit		2	1297	16
294367.2897	392325.5541	19.104	but4		aphoto		1		66
294362.9182	396682.5776	0.746	but4		aphoto		1		57
293051.5703	384649.3424	163.551	but4		aphoto		3		87
293000.0825	383707.1595	210.381	but4		aphoto		3		287
292669.6881	382618.5895	7.096	but4		aphoto		3		85
292253.7398	383553.4358	37.826	but4		aphoto		3		183
292561.1839	381018.0763	84.717	but4		aphoto		1		44
291706.5445	378822.1278	1.103	but4		aphoto		1		29
291474.0146	418376.7009	13.785	wss1		lit		6	1292	214

Figure 15. Attributes table screen in database.

C.4 Database Queries

The Query Builder Tool button is identified by a hammer and question mark (figure 16). By clicking on this tool button the user opens a window where queries on any of the records in the database can be made.

Double clicking on either the Fields or Values selections adds them to the SQL statement. The statement is automatically built by the program and shown in the blank box below the fields and values boxes. Below, and shown in the Query Builder popup window is a sample query for acres > 50.

Clicking on "New Set" creates a selection set from all the records, which will be highlighted in the table. Next to the Query Builder is a button with an arrow pointing upward that will move the selected records to the top of the table.

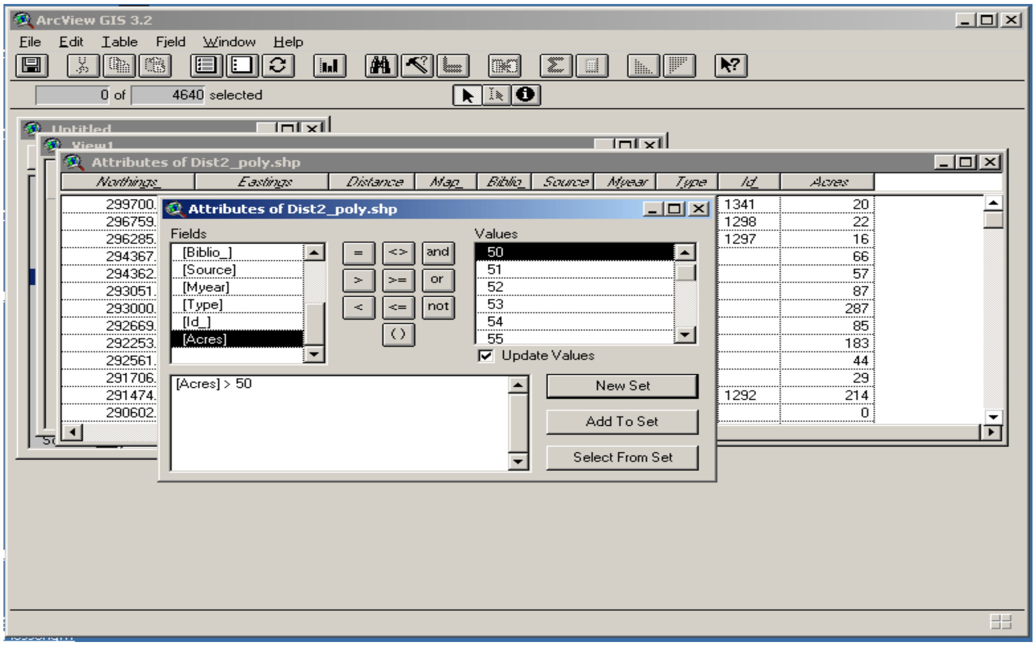
The table can then be edited by selecting "Start editing" from the **Table** drop-down menu. The middle button in the bottom row of buttons allows the user to edit alphanumeric characters in the individual cells. To save the edits, select "Stop editing" from the **Table** drop-down menu. You will be prompted to save edits.

By opening the attribute table and clicking on a field name, that contains numerical values, the user can generate statistics such as sum, mean and standard deviation.

Using ArcView, the user can also link the data to other .dbf (database) format files, such as the MBMG Landslide database, and extract additional information based upon a unique ID number.

Clicking on "Help" and searching for "Join" will provide step by step instructions for this operation and explain the different types of joins that can be performed.

The records can be updated and errors corrected at any time to maintain the integrity of the database. ArcView's versatility in database handling is also very useful in creating customized data sets.



0 of 4640 selected

Northings	Id_	Acres
299700.	1341	20
296759.	1298	22
296285.	1297	16
294367.		66
294362.		57
293051.		87
293000.		287
292669.		85
292253.		183
292561.		44
291706.		29
291474.	1292	214
290602.		0

Fields: [Biblio_], [Source], [Myear], [Type], [Id_], [Acres] (selected: [Acres])

Values: 50, 51, 52, 53, 54, 55 (selected: 50)

☑ Update Values

[Acres] > 50

Figure 16. Database query building screen.

APPENDIX D

GENERAL INFORMATION ABOUT LANDSLIDES AND THEIR CLASSIFICATIONS

D.1.0 INTRODUCTION

Although most slopes appear stable and static, they are actually dynamic, evolving systems. Material on most slopes is constantly moving down the slope at rates that vary from imperceptible creep of soil and rock to thundering avalanches and rockfalls moving at tremendous speeds. Downslope movement is slowest on gentle slopes and increases rapidly with increase in slope.

Vulnerability is the susceptibility or exposure to injury or loss from a hazard. People, structures, community infrastructure (transportation systems, water supply, communication, and electricity), and social systems are all potentially vulnerable. Much of the vulnerability in Montana is a consequence of increasing development of commercial and residential areas, particularly in areas that are steep or landslide prone.

Impact is the effect of the occurrence of the hazard on people and the infrastructures. Once the vulnerability of various communities, areas, and facilities to landsliding has been determined, site-specific evaluations of the potential impacts should be completed.

A *trigger* is an external stimulus such as intense rainfall, earthquake shaking, volcanic eruption, storm waves, or rapid stream erosion, that causes a nearly immediate response in the form of a landslide, by rapidly increasing the stresses or by reducing the strength of the slope materials. Both natural and human-induced changes in the environment can trigger landslides. Human activities affecting landslides are mainly associated with construction, but may also involve changes in slope, vegetative cover and in surface and ground-water regimes. Additional natural factors that can trigger landsliding include climate changes, morphology, and weathering processes.

Driving forces tend to make earth materials move. The most common driving forces are gravity and the weight of the material involved. *Resisting forces* tend to oppose such movement. The most common resisting force is the shear strength of the slope material. In many cases, movement begins from an *immediate cause/trigger* such as earthquake shocks, vibrations, or a sudden increase in the amount of moisture in the material. However, the relationships between the type of earth material, the slope angle, the climate, and the water content are the *real cause* of movement. The resulting movements involve flowing, sliding, falling, subsidence or spread of earth materials at various rates depending on the interrelationship of these factors.

Water is almost always involved (directly or indirectly) with such movements. Probably the most important effects of water are as follows:

- Wave or stream erosion may erode the basal areas of slopes;
- Excess water may cause a rise in water pressure along a potential slide plane;
- Rapid draw down in a reservoir or river may produce unsupported weight in banks;
- Water contributes to the spontaneous liquefaction of clay-rich sediment; and
- Seepage from reservoirs and unlined canals into adjacent slopes may remove cementing materials or increase water pressure.

Phenomena such as earth flows, rockfalls, and avalanches, are natural events that might occur with or without human activity. Human effects on the magnitude and frequency of slope movements vary from insignificant to very significant but are commonly recognizable in urban areas where higher population densities and structural loading from roads, homes, and industries exist.

D.1.1 COMMON CAUSES OF MOVEMENT

Table 16 lists the real causes of landslides found to be most common across the nation.

Table 16. Some common causes of landslides. Modified from Cruden and Varnes, 1996.

Types	Real Causes
Geologic	Weak materials Sensitive materials Weathered materials Jointed or fissured materials Adversely oriented mass discontinuity (bedding, schistosity, etc) Adversely oriented structural discontinuity (fault, unconformity, contact, etc) Contrast in permeability Contrast in stiffness (stiff, dense material over plastic materials)
Morphological	Tectonic or volcanic uplift Fluvial erosion of slope toe Erosion of lateral margins Deposition loading of a slope or its crest Vegetation removal (by forest fire, drought)
Physical	Intense rainfall Rapid snow melt Prolonged exceptional precipitation Rapid drawdown (of floods and tides) Earthquake Shrink-and-swell weathering
Human	Excavation of slope or its toe Loading of slope or its crest Drawdown (of reservoirs) Deforestation Irrigation Mining Artificial vibration Water leakage from utilities

D.2.0 GENERAL TERMS

D.2.1 Mass Wasting/Movement

The various kinds of downhill movement occurring under the force of gravity are collectively called mass wasting. Mass wasting/movement constitutes an important process in denudation of slope surfaces. Abundant evidence shows that on most slopes at least a small amount of downhill movement is going on constantly. Although this motion is imperceptible, the material sometimes slides or flows rapidly. Bedrock and unconsolidated material move in response to the pull of gravity. Gravity can move material only when it is able to overcome the material's internal resistance to being set into motion. Any factor that reduces this resistance can contribute to mass movement.

Mass movements have been grouped according to the classifier's opinion as to what aspects of the phenomena are most important. Mass movements may generally be classified as either rapid or slow; movements can also be differentiated in major groups on the basis of whether the material is transported as a coherent mass or as individual particles. Slow mass movements of unconsolidated material are more difficult to recognize and less fully understood than rapid movements, yet they are extremely important in the sculpturing of the land surface. Because they operate constantly over the entire land surface, and over long periods of time they are probably responsible for the transportation of more material than are rapid and violent movements of rock and soil.

D.2.2 Part Names for a Generalized Landslide

Most landslide literature uses the terms described in table 17 and shown schematically in figure 17.

Table 17. Definition and names of the various parts of an idealized landslide as shown by figure 17, based on Cruden and Varnes, 1996.

Feature Number	Feature Name	Definitions
1	Crown	Practically undisplaced material adjacent to highest parts of main scarp
2	Main Scarp	Steep surface on undisturbed ground at upper edge of landslide caused by movement of displaced material away from undisturbed ground; it is visible part of surface
3	Top	Highest point of contact between displaced material and main scarp
4	Head	Upper parts of landslide along contact between displaced material and main scarp
5	Minor Scarp	Steep surface on displaced material of landslide produced by differential movements within displaced material
6	Main Body	Part of displaced material of landslide that overlies surface of rupture between main scarp and toe of surface
7	Foot	Portion of landslide that has moved beyond toe of surface rupture and overlies original ground surface
8	Tip	Point of toe farthest from top of landslide
9	Toe	Lower, usually curved margin of displaced material of a landslide, most distant from main scarp
10	Surface of Rupture	Surface that forms (or has formed) lower boundary of displaced material
11	Toe of Surface of Rupture	Intersection (usually buried) between lower part of surface of rupture of a landslide and original ground surface
12	Surface of Separation	Part of original ground surface now overlain by foot of landslide
13	Displaced Material	Material displaced from its original position on slope by movement in landslide; forms both depleted mass and ac Intersection (usually buried) between lower part of surface of rupture of a landslide and original ground surface cumulation
14	Zone of Depletion	Area of landslide within which displaced material lies below original ground surface
15	Zone of Accumulation	Area of landslide within which displaced material lies above original ground surface
16	Depletion	Volume bounded by main scarp, depleted mass, and original ground surface
17	Depleted Mass	Volume of displaced material that overlies surface of rupture but underlies original ground surface
18	Accumulation	Volume of displaced material that lies above original ground surface
19	Flank	Undisplaced material adjacent to sides of surface of rupture; compass directions are preferable in describing flanks, but if left and right are used, they refer to flanks as viewed from crown
20	Original Ground Surface	Surface of slope that existed before landslide took place

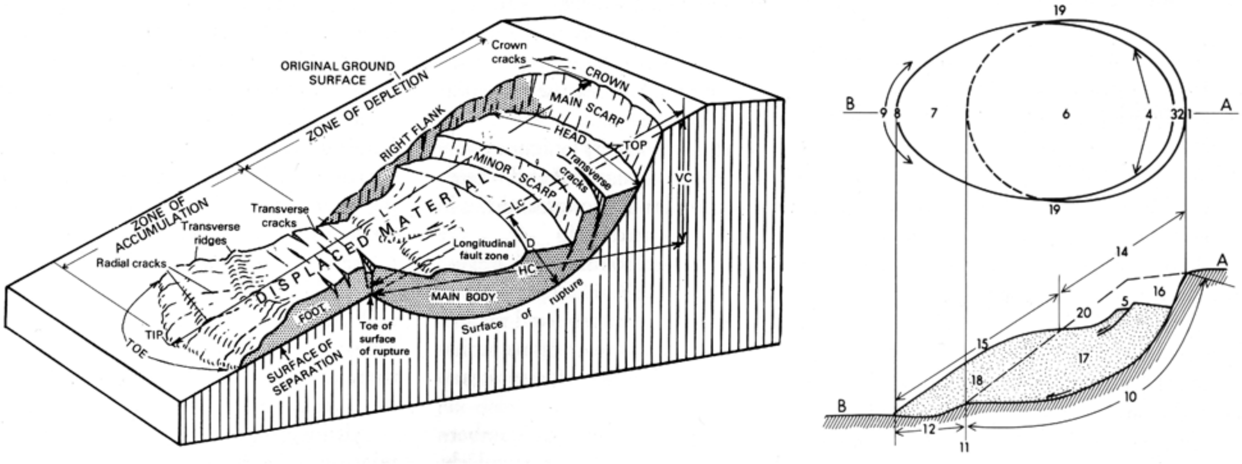


Figure 17. Labeled diagram of parts of landslides (from Cruden and Varnes, 1996).

D.3.0 ADDITIONAL INFORMATION FOR LANDSLIDE CLASSIFICATION

D.3.1 Working Classification System

To provide information needed for MDT and other State or Federal organizations to do risk assessments, a working system of classification for the landslides in this project was adopted. No single landslide classification system is universally accepted. Classification systems have been based on morphology, types of movement, depth, location, engineering parameters and various combinations of these factors, depending on the intended use and background of the developer. Therefore, MBMG and MDT personnel collaborated to decide on the classification system to be used for this study.

Several, viable classification systems have been developed (Sharpe, 1938; Varnes, 1958; Hutchinson, 1968; Varnes, 1978; Turner and Schuster, 1996). The system preferred by most engineers and a majority of geologists was initially developed by Varnes (1958). His classification system was based on the type of displaced material and the mechanism of movement. In 1996, Cruden and Varnes presented a revised and simplified system of classifying landslides, based on the 1978 version of Varnes original 1958 system. This new version retains many of the features of the original classification system. The 1996 version is the basic naming/typing system adopted for use in this study. The classification applied to each movement location combines two descriptive terms. The first term is a broad division of the type of displaced material (rock, debris, earth or soil). The second term is the mechanism of movement (fall, topple, slide, spread or flow).

Cruden and Varnes (1996) have recommended that the use of the terms mud, slump, and rock glacier be discontinued. Various investigators in various disciplines have used different criteria to define these terms. Standard definitions have either not been developed or have not been accepted, so confusion exists in the use of these terms. For these reasons, these terms were not used for this project.

Landslides classified as falls, topples, or spreads were not identified during this project. However, the terms have been kept in the classification system because other districts are expected to contain these types of movement.

D.3.2 Types of Material

Displaced material may range from loose unconsolidated soils to extensive slabs of rock. Any landslide can be classified and described by two terms: the first describing the material being displaced, and the second describing the type of movement involved (Varnes, 1978). Cruden and Varnes (1996) divided the displaced material into two major groups: rock and soil.

Cruden and Varnes (1996) defined rock as a hard or firm, intact, mass that was in its natural place before initiation of movement. Soil was defined as an aggregate of solid particles that was transported or was formed by weathering of rock in place.

Soil can be divided into earth and debris. Cruden and Varnes (1996) defined earth as material in which 80% or more by volume of the particles are smaller than 2 mm. This is the upper limit of sand-size particles recognized by most geologists. Debris is defined as material that contains a significant proportion of coarse particles: 20% to 80% by volume of the particles are larger than 2 mm. This gives an overlap area between 20% and 80% where either term may apply, and determination of the material type will depend on the characteristics of the slide, and the investigator.

D.3.3 Types of Movement

Landslides include a wide range of movement types, from the sliding of a stream bank to the sudden, devastating release of a whole mountainside. Most interpretations of movement characteristics are made after the event is over, which creates some of the confusion in classification. However, the various movements all begin when the forces tending to displace material exceed the resisting strength.

The manner in which movement is distributed through the displaced mass is one of the principal criteria for classifying landslides. Varnes (1978) and Turner and Schuster (1996) list five distinct types of landslide movement: fall, topple, slide, spread, and flow. Additionally, each type of landslide has a number of common modes that may be encountered. The movement types and modes are discussed briefly below.

The distinction between slides and flows is often nebulous, but some generalizations can be proposed:

- Many flows naturally develop as the final stage of a movement that begins as a slide; the distinction between the two is usually unclear.
- The velocity of a landslide depends to a large degree on the amount of water or other buoyant substances in the displaced material.
- In slow earth flows, the original failure of the slope may be in the form of a rotational slide, often when the mass becomes saturated with ground water. If the moving mass is relatively wet, it may slowly bulge forward at its toe by viscous flow and take the form of tongues, superimposed piles of rolled debris, or bulbous toes.

D.3.4 Slide

Cruden and Varnes (1996) defined this type of movement mechanism as a downslope movement of a mass of rock or soil that occurs on surfaces of rupture or on zones of intense shear strain. Sliding can be produced by any event that reduces the internal resistance of the material. Movement does not initially occur simultaneously over the whole area of the surface of rupture; the volume of displacing material enlarges from an area of local failure. The most diagnostic feature of an ancient slide area is hummocky or chaotic land forms. The toe area is characterized by compressional structures unless the displaced mass at the toe has flowed. Tensional cracks are often present behind the slide scarp. These are cracks in the original ground surface, along which the main scarp of the slide will later form, and are the first signs of ground movement. The displaced mass may slide beyond the toe of the surface of rupture, covering the original ground surface of the slope below. The ground surface under the extended mass then becomes a surface of separation. Slides can exhibit varied amounts of internal deformation. Some show purely elastic behavior, the original bedding virtually undisturbed except at the basal shear plane; other slides behave in both an elastic and plastic manner, with semiconsolidated sediment deformed into folds. The recognized *types* of slides are rock slide, debris slide, earth slide, and soil slide. The *modes* of slide movements are translational slide, rotational slide, or compound slide.

Modes

1) *Rotational slide:* A rotational slide is one in which the surface of rupture is curved concavely upward (spoon-shaped) (figure 18) The slide movement is more or less pivotal about the central axis in an arc. The displaced mass may move along the surface with little internal deformation. The scarp formed at the head of the slide may exhibit a recognizable curved surface, but is often almost vertical and unsupported. The crown of the slide mass commonly tilts backward into the cliff/scarp, because the entire mass rotates as it moves. A toe pond may develop in the backward-tilted crown, and the disruption of drainage may keep the displaced material wet and perpetuate the slope movement until a slope of sufficiently low gradient is formed. The toe moves outward and downhill. Further movements may cause retrogression of the slide into the crown. Rotational slides can be divided into two groups based upon the degree of internal deformation:

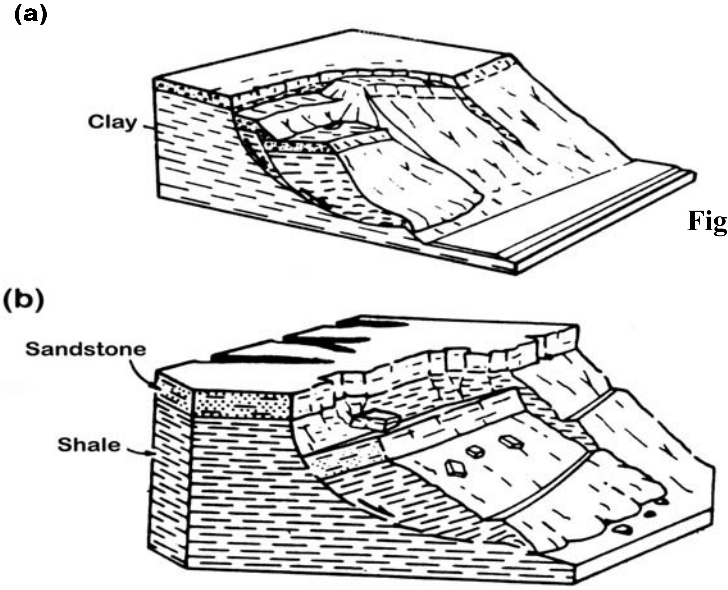


Figure 18. Cross-sectional view of rotational slide movement (from Cruden and Varnes, 1996).

- coherent, in which the mass has moved largely as an undeformed block along a basal plane of slide, and
- incoherent, in which movement has been more pervasive and disruption of beds has occurred. A variety of deformational structures has been recognized: several types of folds, thrusts, balls, hook-shaped over-folds, and rotational slump scars.

2) *Translational slide:* In a translational slide, the mass moves out, or down and out along a planar or undulating surface of rupture that is often roughly parallel to the slope (figure 19). The surface of rupture is often broadly channel shaped. The movement of translational slides is commonly controlled by a surface or surfaces of weakness such as joints, faults, bedding planes and variations in shear strength between layers of

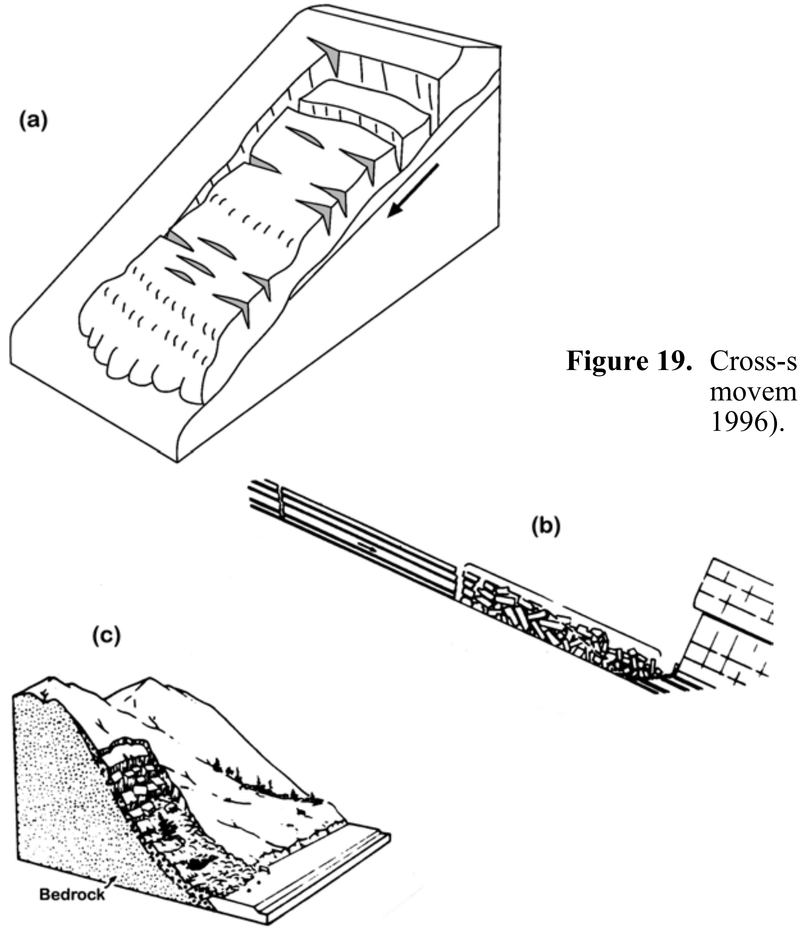


Figure 19. Cross-sectional view of translational slide movement (b and c from Cruden and Varnes, 1996).

bedded deposits, or by the contact between firm bedrock and overlying loose soil. The surfaces of rupture are often broadly channel shaped in cross section. A block glide/slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a single unit; it generally involves a single surface of rupture.

D.3.5 Flow

Cruden and Varnes (1996) define a flow as a spatially continuous movement in which shear surfaces are usually not preserved. Flows typically move as lobes or tongues, and may erode channels. In true flows, particle movement within the displaced mass and the distribution of velocities resemble that in a viscous fluid. The lower boundary of the displaced mass may be a surface along which appreciable differential movement has taken place, or it may be a thick zone of distributed shear. Dry flows can occur in sand or silt, but most flows are saturated with water. Some of the essential criteria defining flow include the following:

- Evidence of internal turbulence, or discrete boundaries of narrow marginal zones of shear. Rates of movement range from imperceptible to very rapid. Displaced material can flow down a relatively gentle slope (2 or 3 degrees). Deposition occurs by a gradual "freezing" of the motion from bottom to top and little segregation occurs.

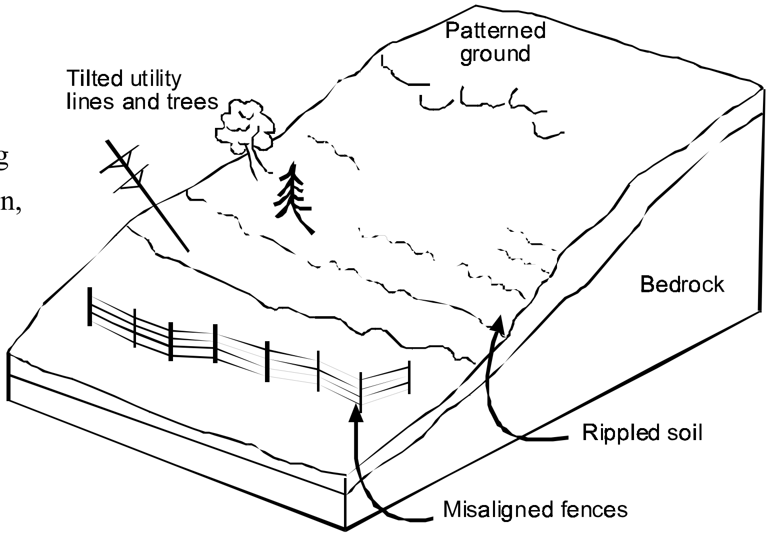
- The features commonly produced are: poor grading, sharp bottoms and tops, no traction structures (though diffuse lamination may develop), basal load casts, fluid escape structures such as dish and pillar structures, sand volcanoes, and convolute laminations.

The recognized *types* of flows are rock flow (sometimes called rock glacier), earth flow, debris flow, and soil flow. The *modes* of flow movements include solifluction, creep, open-face flow, channelized flow, lahar flow, and avalanche.

Modes

1) *Solifluction:* The term solifluction refers to the downslope movement of debris under saturated conditions. This type of movement is not exclusive to cold climates or frozen ground. It is a form of mass-wasting common wherever water cannot escape from a saturated surface layer (figure 20). If soil or regolith is saturated with water, the soggy mass may move downhill a few centimeters per day or per year. The mass of affected material may flow with a kind of rolling motion. Sheets or lobes may cover an entire hillside, and arcuate ridges and troughs often mark the toe. These flows may move down slopes of almost negligible gradient. Flowing almost imperceptibly, this saturated soil forms terraces and lobes that give a slope a stepped appearance (patterned ground).

Figure 20. Cross-sectional view showing features caused by solifluction, creep/heave, flow.



2) *Creep/heave:* Creep is the imperceptibly slow, steady downward movement of slope-forming soil or rock (figure 20). Heave is instrumental in the process of creep. The process functions in the upper several feet of soil, and its effect decreases rapidly with depth. In the heave mechanism, expansion disturbs soil particles perpendicular to the ground surface; when the soil contracts, the vertical attraction of gravity acts on particles thereby adding a lateral/downward component to the movement. Variations in rate occur with differences in slope angle, size of slope material, moisture content, and position on the slope surface. The heave mechanism is essential in some rapid mass movements, especially falls. Soil creep does not shear across immobile rock or soil at depth and is not capable of abrading a buried surface. Although creep is too slow to be observed, the

cumulative results of creep become obvious over a period of years. Stone walls and materials on hillsides show downslope motion by tension cracks, downslope tilt, or visible displacement. Tree trunks may be concave uphill, and the roots of the tree may be unable to keep up with the trunk. Tombstones, fences and utility poles may tilt downhill. Grass may be able to retain a continuous sod cover over an area of soil creep, because movement is typically only a few millimeters per year.

3) *Open-face flow:* In open-face flow the displaced material forms its own path down a valley side/slope onto the gentler slopes at the foot (figure 21). There it may spread out in a thin layer covering a large area, or it may form levees on the sides of the flows and remain within them.

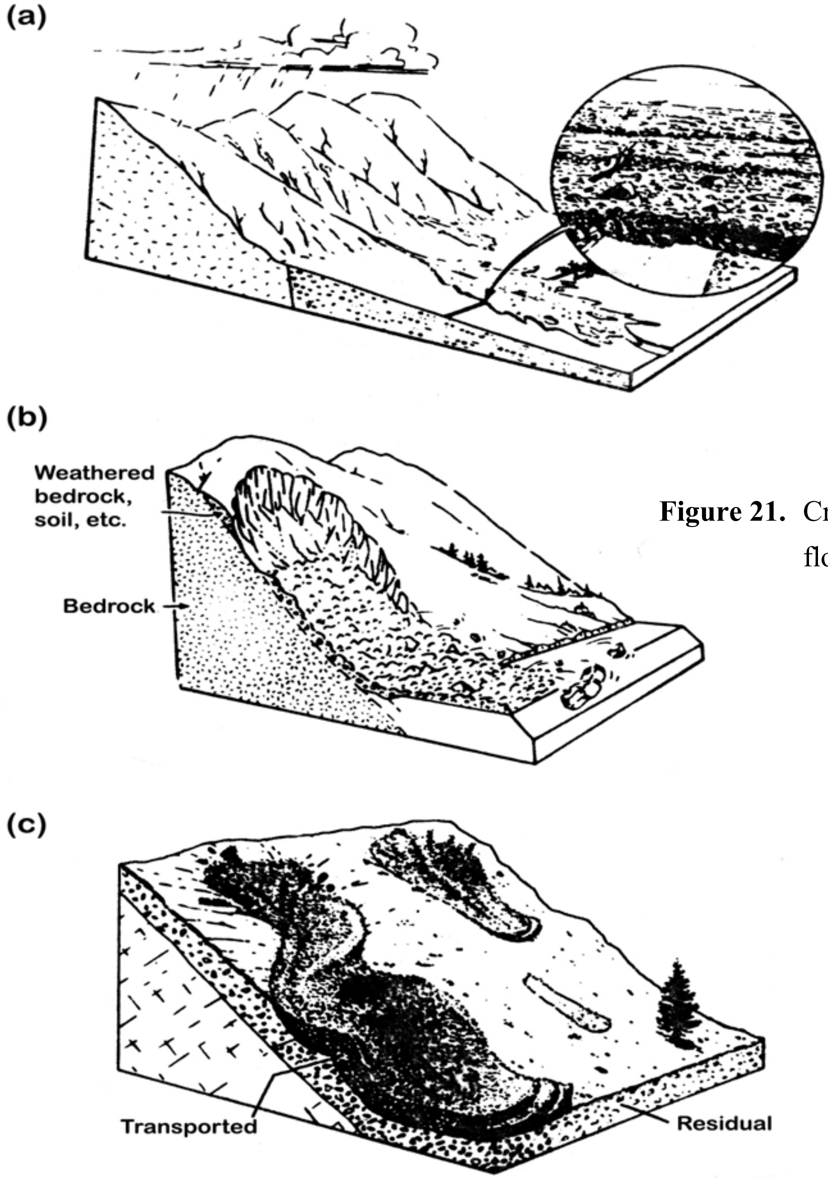


Figure 21. Cross-sectional views of open-face flows (from Cruden and Varnes, 1996).

4) *Channelized flow:* Channelized flows are those that follow existing channels such as creek or stream beds (figure 22). This mode often occurs during or after heavy rainfall.

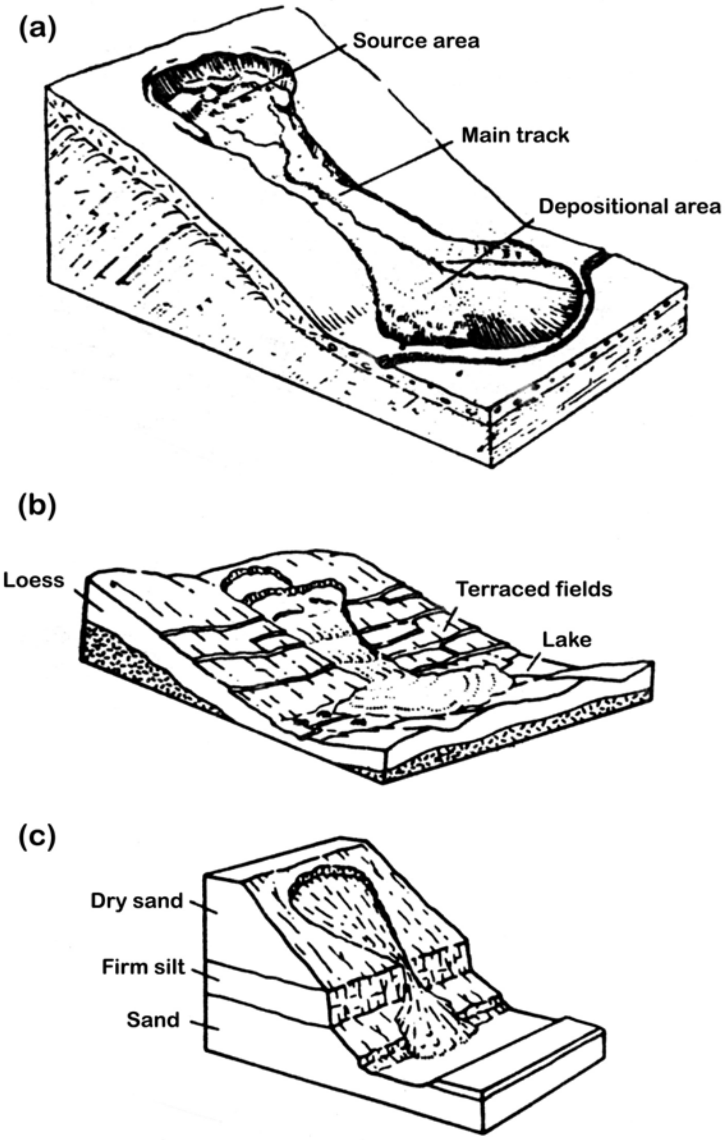


Figure 22. Cross-sectional views of channelized flow (from Cruden and Varnes, 1996).

5) *Lahar:* A lahar is a debris flow formed of volcanic materials, most commonly on the slopes or flanks of active volcanoes.

6) *Avalanche flow:* Avalanches are large, extremely rapid, often open-slope flows. High velocities and inclusion of soil material, vegetation and snow or ice are common. Avalanches commonly have components of slide and fall, and some are thought to move on a cushion of air.

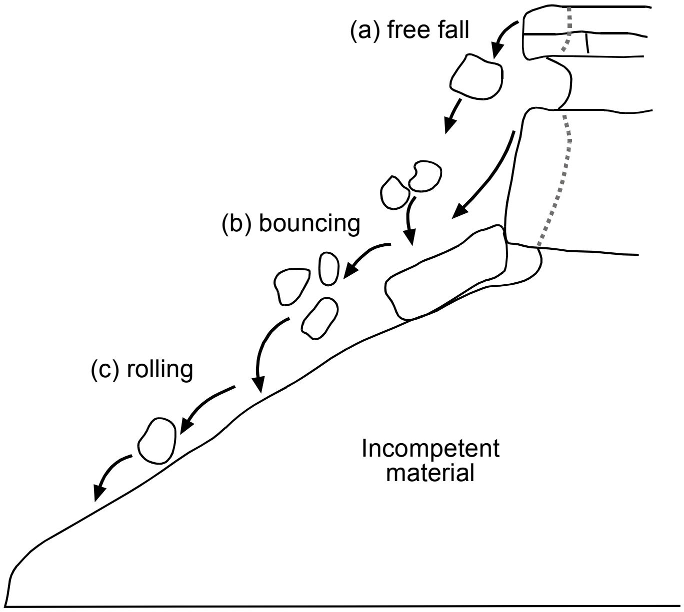
D.3.6 Fall

Cruden and Varnes (1996) define a fall as the detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place. The material descends through the air by dropping, bouncing, or rolling. Movement is very rapid to extremely rapid. Undercutting may occur at the toe of a cliff undergoing wave attack or in eroding riverbanks. The removal of adjacent support will also tend to increase tension in the overhang and so helps to create and expand cracks. The *types* are rock fall, debris fall, earth fall, and soil fall. The *modes* of fall are free fall, bouncing, and rolling. There is a gradual transition to rolling from bouncing as rebounds shorten and incidence angles decrease. Local steepening of the slope may again project rolling particles into the air, restarting the sequence of movement. The falling material may also break up on impact.

Modes

1) *Free fall:* This mode is the fall or drop of the displaced material without striking or coming into contact with the underlying slope or cliff (figure 23). If the slopes below the material being displaced exceed 76 degrees of slope angle, the forward motion of the material is often sufficient for free fall to occur.

Figure 23. Cross-sectional view of fall movement.



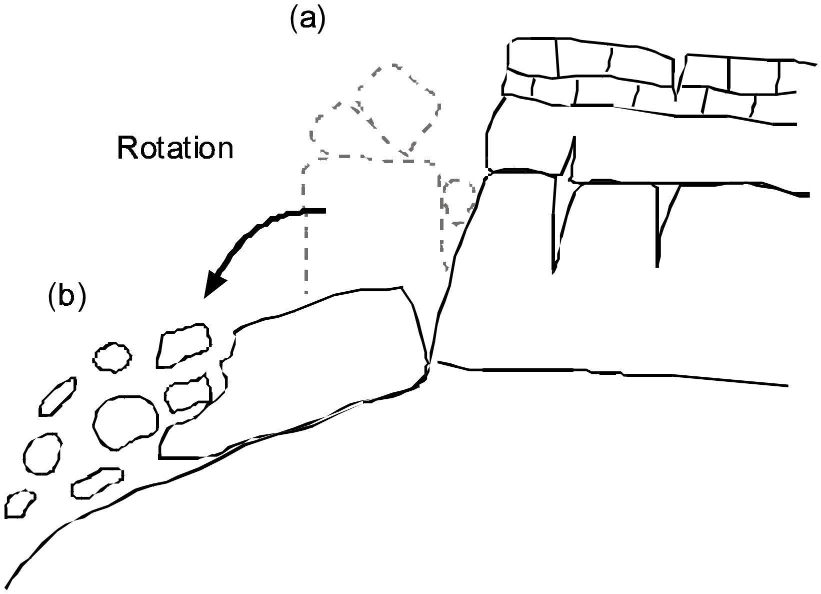
2) *Bouncing:* After the initial fall, the material may strike a slope. If the slope is inclined at less than 76 degrees, the material may stop where it first lands, or rebound from the surface of the basal debris slope. Rebound characteristics resulting from the impact will depend on material properties and the angle between the slope and the trajectory of the falling mass.

3) *Rolling:* The displaced material may also turn end over end after the initial landing, or after bouncing. On long slopes with angles at or below 45 degrees, particles will have movement paths dominated by rolling.

D.3.7 Topple

Cruden and Varnes (1996) stated that this type of failure can be distinguished by the forward rotation of a mass of soil or rock about a point or axis below the center of gravity in the displaced mass (figure 24). The initial top of the displaced material precedes the base down the slope. Toppling may be driven by gravity, by

Figure 24. Cross-sectional view of topple movement.



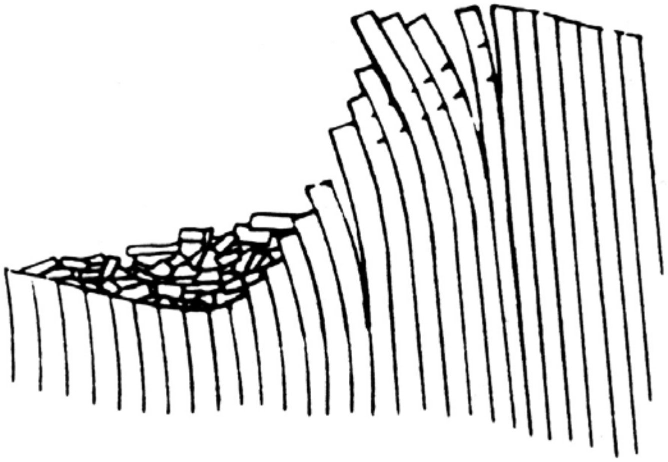
the forces exerted by adjacent units, or by fluids in cracks/joints or interstitial pore space. Topples may lead to falls or slides of the displaced mass, depending on the geometry of the surface of separation, and the orientation and extent of the active discontinuities. Topples range from extremely slow to extremely rapid once the mass has detached; sometimes the displaced mass accelerates throughout the period of movement.

Types of topple include rock topple, debris topple, earth topple and soil topple. *Modes* include flexural topple, block topple, chevron topple, and block-flexure topple.

Modes

1) *Flexural topple:* Flexural toppling occurs in rocks with one preferred discontinuity system, oriented to present a rock slope with columns in continuous flexure as they bend forward (figure 25). Sliding, erosion or undermining of the toe of the displaced mass lets failure begin and it retrogresses backwards causing deep tension cracks. The lower portion of the slope will be covered with disordered blocks. The outward movement of each mass produces interlayer sliding, and back-facing scarps. Flexural toppling occurs most often in slates, phyllites and schists.

Figure 25. Cross-section view of flexural topple (from Cruden and Varnes, 1996).



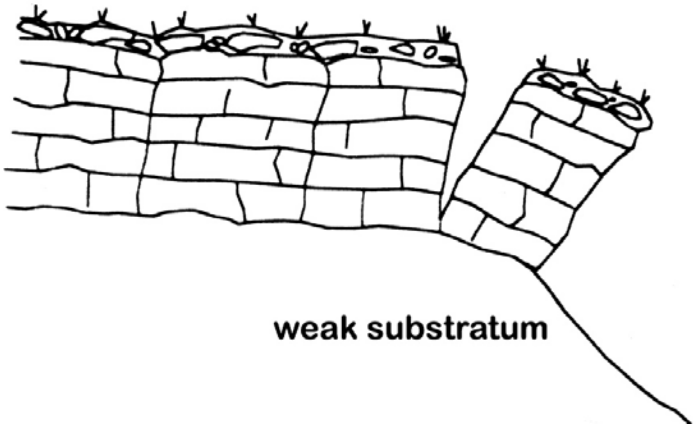


Figure 26. Cross-sectional view of block topple (from Cruden and Varnes, 1996).

2) *Block topple:* Block toppling occurs where individual columns are divided by widely spaced joints (figure 26). The toe of the slope receives a load from overturning masses above, and the toe is pushed forward, permitting further toppling. Thick-bedded sedimentary rocks such as limestone, sandstone, and jointed volcanics exhibit block toppling.

3) *Chevron topple:* Chevron topples are movements in which the dips of the toppled beds are constant. Any change of dip is concentrated at the surface of rupture (figure 27). Chevron topples resemble chevron folds, but occur on steeper slopes. The surface of rupture is often a slide surface.

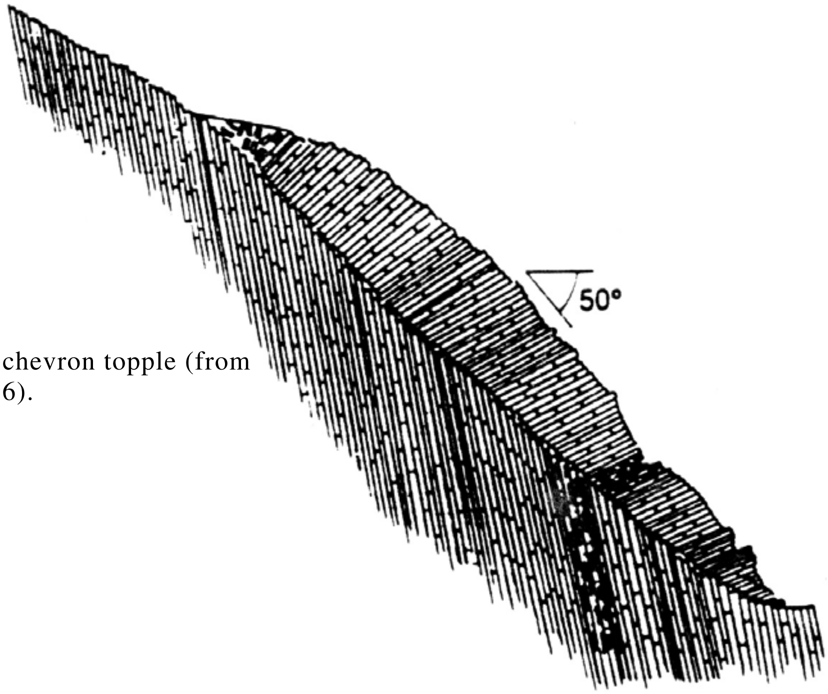


Figure 27. Cross-sectional view of chevron topple (from Cruden and Varnes, 1996).

4) *Block-flexure:* According to Cruden and Varnes (1996), this mode of toppling is characterized by pseudo-continuous flow flexure of long columns through accumulated motions along numerous cross-joints (figure 28). Sliding is distributed along joint surfaces in the toe, while sliding and overturning occur through

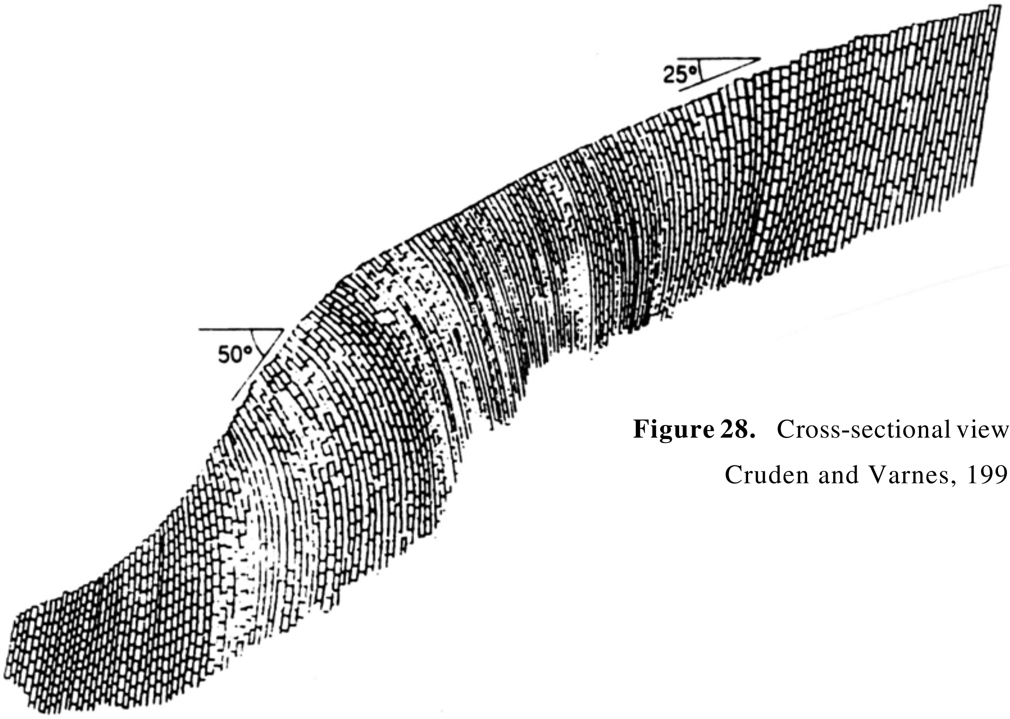


Figure 28. Cross-sectional view of block-flexure (from Cruden and Varnes, 1996).

the rest of the mass. Sliding occurs because accumulated overturning steepens the cross-joints. Interbedded sandstone, shale, and thin-bedded limestone often exhibit block-flexure topples.

D.3.8 Spread

Originally, the term, spread, was used for a sudden movement on water-bearing seams of sand or silt overlain by homogeneous clays or loaded by fills (figure 29, 30). Cruden and Varnes (1996) defined this mode as an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material. Spreads may be caused by liquefaction or extrusion of the softer material. Movements in cohesive soils overlying liquefied materials flow plastically, and may also subside, translate, rotate, disintegrate, or liquefy and flow. Spreads are distinctive because they usually occur on very gentle slopes (between 0.5 and 5%). Spreading in fine-grained materials on shallow slopes is usually progressive; the failure starts suddenly in a small area and spreads rapidly. The types recognized are rock spread, earth spread, debris spread, and soil spread. The modes include block spread and liquefaction spread.

Modes

1) *Block spread:* Cruden and Varnes (1996) state that block spreads involve a thick layer of rock that overlies softer materials where the strong upper layer fractures and separates into sections (figure 29 a,b). The soft underlying material is squeezed into the cracks between the sections and the cracks may be filled with broken, displaced material. Typical rates of movement are extremely slow, and may extend many kilometers back from the edges of plateaus and escarpments.

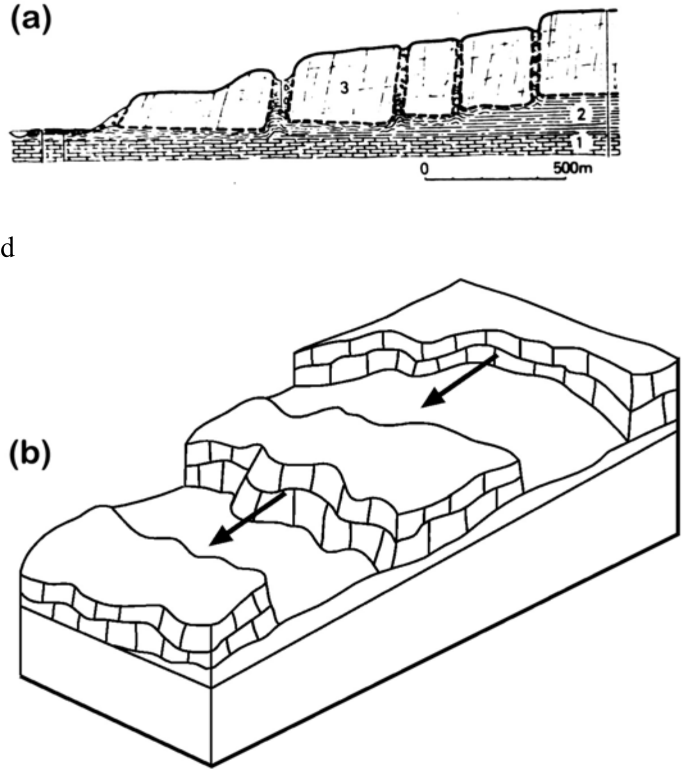


Figure 29. Cross-sectional view of block spread movement (29a from Cruden and Varnes, 1996).

2) *Liquefaction spread:* According to Cruden and Varnes (1996), liquefaction spreads commonly form in sensitive clays and silts that have lost strength from disturbances that damaged their structure (figure 30 a, b). Movement is translational and often starts at a stream bank or a shoreline and extends away from it (retrogresses). If the flowing layer is thick, blocks may sink into it, forming grabens. Movement can begin suddenly and reach very rapid velocities.

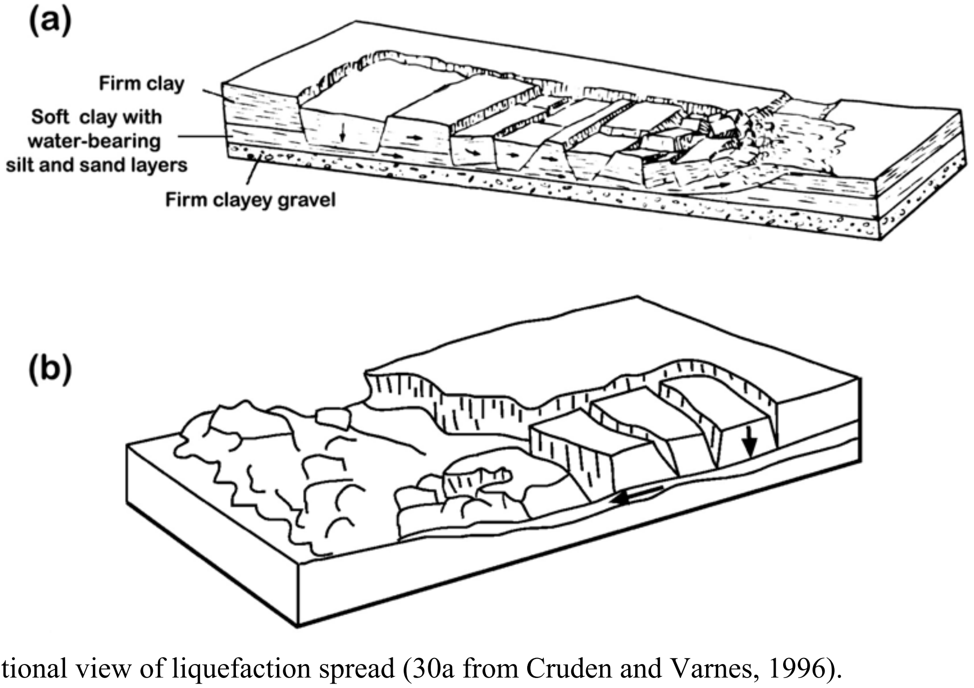


Figure 30. Cross-sectional view of liquefaction spread (30a from Cruden and Varnes, 1996).

D.3.9 Complex/Compound Movement

A landslide may include more than one type of movement, or more than one type of failure. Although each type could function alone, two or more are probably involved to some extent in most natural slope failures. Transitions from one movement type to another are common, and many landslides can only be explained by some combination of the primary types of movements. To describe such movements, Cruden and Varnes (1996) proposed using the terms complex and composite.

D.3.9.1 Complex Falls

Large falls may begin additional movements such as sturzstrom (discussed below), flows and avalanches. Avalanche movements combine elements of fall and flow and sometimes slide. Falls may also be initiated by either a slide or flow.

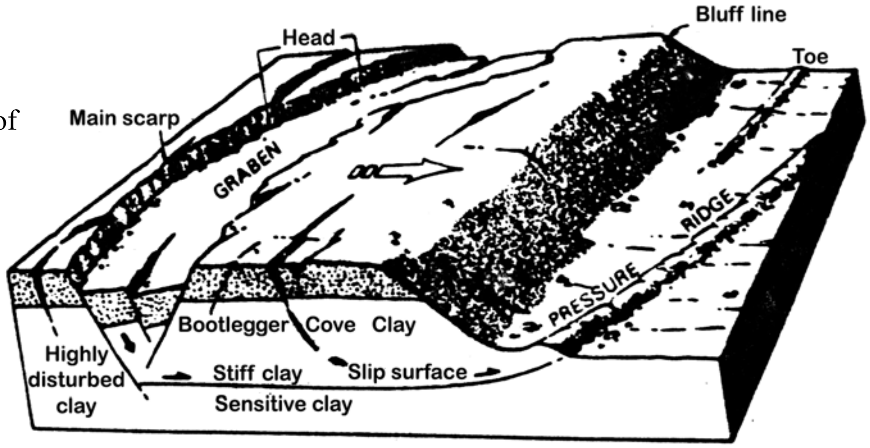
D.3.9.2 Complex and Composite Topples

In complex topples several distinct movements may occur as it progresses, and a modification of water flows within the mass can occur. Toppling may also be caused by earlier slide or flow movements such as slide head toppling, slide base toppling, slide toe toppling and tension crack toppling.

D.3.9.3 Complex and Composite Slides

Slides may retrogress by falling or sliding while advancing by sliding (figure 31). Such slides are composite or complex in style of activity and in the breakdown of displaced material into earth or debris. Cruden and Varnes (1996) state that at least three phenomena can cause these behaviors: impact collapse, dynamic liquefaction, and static liquefaction. The displaced material initially broken by slide movements may subsequently begin to flow. These slides are intermediate between rotational and translational slides. Displacement along complexly curved surfaces of rupture produce internal deformations and shear along surfaces within the displaced material and often results in the formation of intermediate scarps. Abrupt decreases in downslope dips of surfaces of rupture may be marked by uphill-facing scarps in displaced masses and the subsidence of blocks of displaced material to form depressed areas (grabens). A compound slide (figure 31) often indicates the presence of a weak layer or boundary between weathered and unweathered material that will control the location of the surface of rupture.

Figure 31. Cross-sectional view of a complex slide (from Cruden and Varnes, 1996).



D.3.9.4 Complex Spreads

Spreads are actually complex movements, however, according to Cruden and Varnes (1996), they are sufficiently common in certain materials and geological situations that the concept of a spread should be recognized as a separate type of movement. Cambers and valley bulging are spread movements that combine spread and topple.

D.3.9.5 Complex and Composite Flows

Visible, extensively striated or slickensided lateral margins or surfaces of rupture may cause the landslide to be termed an earth slide. If the displaced mass is strongly deformed internally, the landslide may be termed an earth flow. If the landslide shows both modes of deformation, it is composite. Movements that may have been initiated by sliding on the bedding or schistosity of a rock mass and ends in flow forms of movement are complex flows.

D.3.9.6 Sturzstrom (complex, extremely rapid, rock fall-rock flow)

When rocks fall or flow down a steep slope, the material disintegrates as it crashes into the relatively flat surface at the base of the slope. From there, the rocks travel as masses of broken debris, moving at high velocities over the gentler slopes in the valley bottoms. It has been proposed that these large masses slide continuously on a layer of compressed air that is trapped beneath the debris as it comes to the bottom of the steep slope, or that it moves primarily by flow. The highest strata involved in the fall are commonly contained in the rear portion of the deposited debris. This distribution negates viscous flow. The flow mechanism also differs from viscous transport in that individual particles are dispersed in a dust-laden cloud, and the kinetic energy driving the flow is transferred from grain to grain as they collide and push one another forward. The entire mass moves simultaneously until all the original energy is dissipated. As displaced material is broken apart, these movements may end as debris flows.

D.4 STATE OF ACTIVITY

The descriptive terms proposed by Cruden and Varnes (1996) are presented in table 18. To describe a landslide, the terms are added from the tables in this order: activity, description of first movement, description of second movement, etc., material, type of movement. Up to three terms, one from each column in table 18, can be added to describe the activity of a slide, i.e. reactivated, widening, multiple, earth slide. The styles of movement include complex, composite, multiple, successive, and single:

- A *complex* landslide exhibits at least two types of movement and is limited to cases in which the various movements occur in sequence.
- A *composite* landslide exhibits at least two types of movement, but the movement occurs in different areas of the displaced mass, often simultaneously.
- A *multiple* landslide exhibits repeated movements of the same type, often following enlargement of the surface of rupture.

Table 18. Proposed terms for describing the activity of a landslide (Cruden and Varnes, 1996).

Activity State	Distribution	Style
Active	Advancing	Complex
Reactivated	Retrogressive	Composite
Suspended	Widening	Multiple
Inactive	Enlarging	Successive
Dormant	Confined	Single
Abandoned	Diminishing	
Stabilized	Moving	
Relict		

- In a *successive* landslide, movement is identical in type to an earlier movement but does not involve previously displaced material or share a surface of rupture with it.
- A *single* landslide consists of one movement of displaced material.

D.5 DESCRIPTION OF MOVEMENT EPISODES

Description of the first movement of a landslide could contain two additional terms to describe the rate of movement, and the water content, i.e. extremely rapid, dry, rock fall (table 19). If information is available on later movements, terms can be added in the same order to describe each of them. An example of a complete name encompassing the first and second movement is: dormant, retrogressive, successive, moderate, wet, reactivated, retrogressive successive, wet, debris flow. The amount and type of information available on each slide will determine the number of the terms necessary to describe each movement.

Table 19. Proposed terms for describing the first and subsequent movements of a landslide (Cruden and Varnes, 1996).

Description of First Movement			
Rate	Water Content	Material	Type
Extremely Rapid	Dry	Rock	Fall
Very Rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very Wet	Debris	Spread
Slow			Flow
Very Slow			
Extremely Slow			
Description of Second Movement, etc.			
Rate	Water Content	Material	Type
Extremely Rapid	Dry	Rock	Fall
Very Rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very Wet	Debris	Spread
Slow			Flow
Very Slow			
Extremely Slow			

D.6.0 RATES OF MOVEMENT

The rate-of-movement scale developed by Varnes (1978) is shown in table 20. This scale is changed from Varnes original scale only by the addition of metric measurements. A modified scale was developed and proposed by Cruden and Varnes (1996), and is presented in table 21. In this version, the divisions of the scale have been adjusted to increase in multiples of 100. Thus, the scale spans 10 orders of magnitude. Both scales are currently in use.

Table 20. Rate of movement scale developed by Varnes (1958) and as modified by Varnes (1978).

Velocity (ft/sec)	Descriptive Term	Typical Velocity
102 101		10ft/sec = 3 m/sec
	Very Rapid	
100 10^{-1}		1ft/min = 0.3 m/min
10^{-2}	Rapid	
10^{-3} 10^{-4} 10^{-5}		5ft/day = 1.5 m/day
	Moderate	
10^{-6}		5ft/mo = 1.5 m/month
	Slow	
10^{-7}		5ft/year = 1.5 m/year
	Very Slow	
10^{-8}		1 ft/year = 60 mm/year
10^{-9}		Imperceptible

Table 21. Velocity classification taken from Cruden and Varnes (1996).

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity
7	Extremely Rapid		
		$5x10^{3}$	5 m/sec
6	Very Rapid		
		$5x10^{1}$	3 m/min
5	Rapid		
		$5x10^{-1}$	1.8 m/hr
4	Moderate		
		$5x10^{-3}$	13 m/mo
3	Slow		
		$5x10^{-5}$	1.6 m/yr
2	Very Slow		
		$5x10^{-7}$	16 mm/yr
1	Extremely Slow		

D.7.0 DESTRUCTIVE POTENTIAL

The expected degree of potential loss due to landsliding or any other natural phenomenon can be estimated as the product of hazard and vulnerability. According to Cruden and Varnes (1996), hazard is the probability of the occurrence of the phenomenon within a given area; vulnerability is the degree of loss in the given area of elements at risk (population, properties, and economic activities). Using this definition, the vulnerability might be expected to increase with velocity. Table 22 lists the probable destructive potential of the velocity classes given in table 21. However, each landslide area must be investigated separately because the damage sustained depends upon both the distortion of the displaced mass and the type of landslide.

Table 22. Landslide velocity classifications and destructive potential.

Landslide Velocity Class	Probable Destructive Significance
7	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths, escape unlikely
6	Some lives lost; velocity too great to permit all persons to escape.
5	Escape evacuation possible; structures, possessions, and equipment destroyed.
4	Some temporary and insensitive structures can be temporarily maintained.
3	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase.
2	Some permanent structures undamaged by movement.
1	Imperceptible without instruments; construction possible with precautions.

APPENDIX E

GENERAL DEFINITIONS OF LANDSLIDE TERMINOLOGY

Abandoned landslide: Mass movement in which the stream that has been eroding the toe changes course.

Advancing landslide: Mass movement in which the surface of rupture is extending in the direction of movement.

Ancient or fossil landslide: Mass movements that remain visible in the landscape for thousands of years after they have moved and then stabilized.

Active landslide: Those mass-movements that are currently moving, including first-time movements and reactivations.

Alluvium: A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other running water, as sorted or semi-sorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope; during time of flood.

Avalanche: A large mass of snow, ice, soil, rock, debris or a mixture of these materials, falling, sliding, or flowing very rapidly downslope under the force of gravity. Velocities may exceed 500 km/hr.

Bounce: A mode of falling. If a falling mass or rock strikes a slope inclined at less than a 76 degree angle, rebound (bounce) from the slope may occur. The angle and length of the rebound will depend on material properties of both the displacing material and the slope material.

Buried landslide: A landslide movement that has been covered by other deposits.

Colluvium: A general term applied to any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow continuous downslope creep, usually collecting at the base of gentle slopes or hillsides. Talus and cliff debris are included in such deposits.

Complex landslide: Mass movement with at least two types of movement; term is limited to cases in which the various movements occur in sequence

Composite landslide: Former synonym for complex. Current usage is for mass movement in which different types of movement occur in different areas of the displaced mass, sometimes simultaneously.

Confined landslide: Mass movement in which a scarp is present, but no visible surface of rupture is present in the foot of the displaced mass.

Creep: Applied to soils and surficial material, a generally imperceptible, continuous and non-accelerating downward and outward movement of slope forming material characterized by slow flowing, sliding, or slipping of earth materials downslope. Movement is typically only a few millimeters per year. Applied to bed rock, slow deformation of near surface material in a downslope direction that results from long application of a stress. Part of such creep is permanent deformation, while part of the deformation is elastic and the specimen can recover. This type of movement can operate even on gentle slopes with a protective cover of grass and trees. The term should not be limited by a presumption of mechanism, depth, velocity, profile, thickness of creep zone, or lateral extent.

Debris: Fragments arising from disintegration of rocks, sand, earth, soil and sometimes organic matter in a heterogeneous mass. Any surficial accumulation of loose material detached from rock masses by chemical and mechanical means. Loose surficial material that contains a significant proportion of coarse fragment material; 20% to 80% of the particles are larger than 2mm, and the remainder are less than 2 mm.

Debris avalanche: The very rapid and usually sudden sliding, falling, or flowing of incoherent, unsorted mixtures of soil, vegetable matter, and weathered bedrock downslope.

Debris fall: A relatively free downward or forward movement of unconsolidated or poorly consolidated debris from a cliff, cave, or arch. The relatively free collapse of predominantly unconsolidated or weathered material. Especially common along the undercut banks of streams.

Debris flow: Moderately rapid to rapid downslope movement by flowage of debris often involving saturated, unconsolidated material that has become unstable. Debris flows have 20–80 percent particles coarser than sand size. Often found on alluvial fans. Deposits are poorly sorted or non-sorted and coarse grained, and may include cobbles and boulders. Slow debris flows may move less than 1 m per year; rapid ones reach 160 km per hour.

Debris slide: The slow to rapid movement of comparatively dry to wet, largely unconsolidated, debris that slides downward to produce an irregular topography of low hummocks with small, intervening depressions. The displacing mass does not show backward rotation but slides forward. The moving mass of a debris slide may be greatly deformed or consists of many small movements.

Diminishing landslide: Mass movements in which the volume of material being displaced grows less with time and those in which no trend is obvious.

Distribution of activity: Term used to describe broadly where the landslide is moving.

Dormant landslide: Inactive landslide in which the causes of movement remain apparent

Driving forces: Those forces that tend to make earth material slide. The sum of the remote tensile stress, gravity and internal fluid pressure acting on a crack or joint.

Dry: No moisture apparent in displaced material.

Earth: A general term for the solid materials that make up the physical globe, as distinct from water and air. Material in which 80% or more of the particles are smaller than 2mm, the upper limit of sand-size particles.

Earth fall: Very-rapid to rapid movement of earth by dropping or falling.

Earth flow: Moderately rapid to rapid downslope movement of earth often involving saturated, unconsolidated material that has become unstable and is characterized by downslope translation of earth over a discrete basal shear surface. Earth flows have 80 or more percent particles of sand size. Overall, little or no rotation of the slide mass occurs during displacement, sometimes forming a step-like terrace at the top and a bulging toe at the base.

Earthquake: A natural local trembling, shaking, undulating, or sudden shock of the surface of the Earth, sometimes accompanied by fissuring or by permanent change of level at the surface, occurring to depths up to of 420 miles (700 kilometers), caused by the abrupt release of slowly accumulated strain.

Earth slide: The downslope movement of a part of an earth slope or embankment. The major part of the material moves in a somewhat fluid manner by slide mechanism. The displacing mass may range from dry to wet, and movement ranges from rapid to slow. The displacing mass does not show backward rotation.

Enlarging landslide: Landslide in which the surface of rupture is continually adding to the volume of material displaced.

Fall: To drop or collapse. A fall starts with the detachment of soil or rock from a steep slope along a surface on which little or no displacement takes place. The collapsing material then descends, mainly through the air. The falling or collapsing mass may break apart on impact. It is the fastest form of landsliding with movement rates from very rapid to extremely rapid. Falls are not guided by any underlying slip surface.

Fault: A break or fracture (or fracture system) in bedrock that has experienced movement along its length. The adjacent rock surfaces are differentially displaced relative to each other and generally parallel to the fracture. The displacement may be a few inches or many miles.

Flood plain: The relatively smooth or flat topography adjacent to a stream in a river valley that has been produced by a combination of overbank flow and lateral migration of meander bends that is often covered by water at the flood stage. It is built of sediment carried during the present regimen of the stream and dropped in the slack water beyond the influence of the swiftest current.

Flow: A form of movement in unconsolidated material that exhibits a continuity of motion and a plastic or semi-fluid character. Water is usually required for most types of flow, but dry flows do exist. Movement often results in destruction of bedding coherence so that the individual grains move in a fluid medium and propel it. Evidence of internal turbulence, and either discrete boundaries or narrow marginal zones of shearing are defining criteria. Creep, solifluction, earth flow, mud flow, debris flow, and sturzstrom are modes of flow. The mass of material moved by a flow.

Fragment: A rock or mineral particle larger than a sand grain. A piece of rock that has been detached or broken from a pre-existing mass. A component of bedrock consisting of sand grains that are abraded particles of igneous, sedimentary, or metamorphic rocks and has recognizable characteristics of its origin.

Free fall: Mode of falling movements in which the displacing material collapses and drops through the open air. The forward motion of masses of soil or rock is often sufficient for free fall if the slopes below the mass exceed 76 degrees.

Frost creep: Creep caused by the ratchet-like motion of particles during alternating freeze-thaw cycles. Process of mechanical weathering caused by repeated cycles of freezing and thawing. Expansion of water during freezing cycle provides energy for the process.

Inactive landslide: A landslide that has not moved within the last annual cycle of seasons.

Impact: The effect of the occurrence of the hazard on people and the infrastructure.

Lahar: A debris flow composed largely of volcaniclastic materials often located on the flank of a volcano. The debris carried in the flow includes pyroclasts, blocks from primary lava flows, and epiclastic material.

Landslide: A general term covering a wide variety of mass-wasting land forms and processes involving the downslope transport, under gravitational influence, of soil and rock material en masse. A generalized or popularized term for the movement of a mass of rock, debris or earth down a slope, but not limited to the land surface, nor the 'slide' movement mechanism. The mass of earth, rock or debris that moves down slope. Movement mechanisms include flow, spread, slide, topple, or fall. Sometimes limited to all perceptible or sudden forms of movement, but increasingly extended to include imperceptible and slow movements, as well.

Liquefaction: Movement that occurs when a loosely packed sediment collapses, the grains temporarily lose contact with each other and the particle weight is transferred to the pore water. Temporary excess pore water pressures are induced and downslope gravitational stresses cause sediment to flow.

Mass-transport/wasting/flow/movement: A general or collective term for a variety of processes by which masses of material are moved by gravity either slowly or quickly downslope. It bridges the gap between weathering (defined as occurring in place), and erosion (requires transport by some agent or medium). This *en masse* downslope movement may contain various amounts of water. Spontaneous movement of slope material.

Moist: Contains some water but no free water; the displaced material may behave as a plastic solid but does not flow.

Moving landslide: Mass movement in which displaced materials continue to move but whose surface of rupture shows no visible changes.

Mud: Very generalized term not recommended for use. A collective term for sediment mixed with water whose particle sizes lie within the range of various classes of silt and clay, but may include varying amounts of sand and sometimes with organic matter and rock debris included. Consistency ranges from semi-fluid to soft and plastic.

Multiple landslide: Type of landslide which shows repeated movements of the same type, often following enlargement of the surface of rupture. The newly displaced masses are in contact with previously displaced masses and often share a surface of rupture.

Progressive failure: The process by which the surface of rupture extends headward in some mass movements.

Progressive landslide: Mass movement in which the surface of rupture is enlarging in two or more directions. Term has been used for both advancing and retrogressive movements. Term enlarging recommended for replacement of this term.

Reactivated landslide: A mass-movement that is active again after being inactive.

Regolith: A general term for the layer or mantle of fragmental and unconsolidated rock material, whether residual or transported and of highly varied character, that nearly everywhere forms the surface of the land and overlies or covers the bedrock. Term includes rock debris of all kind, volcanic ash, glacial drift, alluvium, loess, and eolian deposits, vegetal accumulations, and soil.

Relict landslide: Mass movements that have clearly developed under different geomorphic or climatic conditions, perhaps thousands of years ago.

Retrogressive landslide: Mass movement in which the surface of rupture is extending in the direction opposite from the movement direction.

Rock/bedrock: A hard or firm mass that was intact and in its natural place before initiation of movement. Commonly used term for any hard, compact material derived from the earth. A consolidated or unconsolidated aggregate of mineral grains consisting of one or more mineral species having some degree of chemical and mineralogic constancy. An aggregate of one or more minerals; or a body of undifferentiated mineral matter constituting an essential and appreciable part of the Earth's crust. Includes loose incoherent masses, such as a bed of sand, gravel, clay, or volcanic ash, as well as the very firm, hard and solid masses of granite, sandstone, limestone, etc.

Rock avalanche: An extremely rapid, dry flow of rock fragments. Sometimes called sturzstrom. Rock avalanches typically result from large rock falls and slides.

Rock creep: Imperceptible and non-accelerating downslope movement of unweathered joint blocks. Slow, permanent internal rock deformation (strain) under low stress. A form of slow flowage in rock materials evident in the downhill bending of layers of bedded or foliated rock and the slow downslope migration of large blocks of rock away from the parent outcrop.

Rock fall: The relatively free fall of a newly detached segment of bedrock of any size from a cliff, steep slope, cave, or arch. The rock material moving in or moved by a rockfall. Movement may be straight down, or in a series of leaps and bounds down the slope. The moving rock material typically accumulates at the cliff base in the form of talus cones.

Rock flow: The term given to a slope failure when there is a general breakdown of the rock mass. When such a rock mass is subjected to shear stresses sufficient to break down the cement, or to cause crushing of the angularities and points of the rock blocks, the block will move down the slope until it forms a more stable slope. Characteristic features include chaotic distribution of large blocks, flow morphology and internal structure, relative thinness in comparison to large areal extent, high porosity, angularity of fragments, and lobate form. Sometimes called rock glaciers.

Rock glacier: Term recommended for discontinued use because of the different definitions that have developed, and disagreements about the nature of the features that should be included under this name. Now considered a rock flow.

Rock slide: The downward and usually rapid movement of newly detached segments of the bedrock that move over a surface of weakness, such as bedding, joint, fault surfaces, or any other plane of separation. The rock mass that has attained its present condition by such a movement. The moving mass is commonly greatly deformed and usually beaks up into many small independent units.

Rolling: Mode of fall characterized by an end over end movement subsequent to the mass striking a slope inclined at less than 45 degrees.

Rotational slide: A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to that slope so that the top of the moving material often exhibits a reversed slope facing uphill. The mass of material that slipped down during, or produced by the rotational slide movement. The displacing mass commonly retains some or all of its internal (bedding) coherence resulting in little or no deformation due to the movement. Sometimes called slump.

Sand: Sediment particles between 0.02 mm and 2 mm in diameter. A loose aggregate of unlithified mineral or rock particles of sand size. A detrital fragment or mineral particle smaller than a granule and larger than a coarse silt grain, or a size between that at the lower limit of visibility of individual particles with the unaided eye and that of the head of a small wooden match. Material most commonly composed of quartz resulting from rock disintegration, but the particles may be any mineral composition or mixture of rock or mineral fragments. The term has also been used for a soil containing 90% or more of sand.

Scarp: A steep slope or cliff commonly associated with landslides or earthquakes. A cliff or line of cliffs, or steep slopes, generally of some extent, that separates surfaces lying at different levels, as along the margin of a plateau or mesa. A scarp may be produced by erosion or by faulting. The steep face presented by the abrupt termination of strata. The term is an abbreviated form of escarpment, although scarp is more often applied to cliffs formed by faulting. A scarp may be of any height.

Sediment: Mineral matter and organic matter derived directly or indirectly from pre-existing rock by weathering; and that is transported or deposited by air, water, or ice, or that accumulates by other natural agents, such as chemical precipitation from solution or secretion by organisms, and that forms in layers on the Earth's surface at ordinary temperatures in a loose, unconsolidated form; as sand, gavel, silt, mud, till, loess, alluvium.

Single landslide: Landslide that consists of one movement of displaced material, often as an unbroken block.

Slide: Downslope movement of debris, rock or earth occurring dominantly on surfaces of rupture. Rotational or planar mass movement resulting from failure under shear stress along one or more surfaces that are either visible or may reasonable be inferred. The moving mass may or may not be greatly deformed. The track of bare rock or furrowed earth left by a slide. The mass of material moved in or deposited by a slide. Modes of slide are translational and rotational.

Slump: Term recommended for discontinued use. A type of landslide characterized by the downward slip of a mass of rock along a curved slide plane. A rotational slide.

Soil: An aggregate of solid particles, generally of minerals, rocks and organic matter, that either was transported or was formed by weathering of rock in place. Gases or liquids filling the pores form part of the soil. Any loose or unconsolidated material lying over bedrock and capable of supporting vegetation. Soil can range in thickness from a few inches to many feet, and nearly everywhere forms the surface of the ground. Soil composition varies with climate, plant types present, animal life, time, slope of land and parent material. Soil can be subdivided into earth and debris.

Soil creep: Imperceptible and nonaccelerating downslope movement of weathered soil debris on slopes that may be very gentle but are often steep, resulting from natural causes such as the continued agitation and disturbance of the particles by activities such as frost action, weathering, temperature changes, or wetting and drying of the soil, rainfall, or sheet wash. Movement is extremely slow, typically only a few millimeters per year.

Soil fall: A fall involving soil materials.

Soil flow: A landslide or flow involving soil materials.

Solifluction: Mode of flow. Common wherever water cannot escape from a saturated surface layer of soil or debris. The mass may move downhill a few centimeters per day or per year, typically 0.5 to 5.0 cm/yr., or slightly faster than typical soil creep. The process of slow viscous flowage from higher to lower ground of masses of regolith saturated with water above an impervious or confining layer (frozen ground) that acts as a downward barrier to water percolation. Characteristic of saturated soils in high latitudes. Commonly initiated by thawing cycles or wet and dry cycles. It may be augmented by meltwater or extended periods of freezing rain. The term has been extended to temperate and tropical regions.

Stabilized: If the toe of the slope has been protected against erosion by bank armoring or if other artificial remedial measures have stopped the movement, the landslide can be described as stabilized.

State of activity: Terms to describe what it known about the timing of movements.

Style of activity: Terms that indicate the manner in which different movements contribute to the landslide.

Successive landslide: Mass movement that shows repeated movement that is identical to previous movement, but does not share displaced material, nor a surface of rupture.

Sturzstrom: An extremely rapid flow of dry debris created by large falls and slides. May reach velocities over 50 m/sec. Also called rock-fall avalanche or rock avalanche. The moving mass is believed to travel on a cushion of air. During the downslope movement, fragments may become further broken or pulverized and additional regolith and vegetation may be add to the moving mass.

Suspended landslide: Mass movements that have moved within the last annual cycle of seasons but that are not moving at present.

Talus: Slope established by accumulation of rock fragments from rock falls at the foot of a cliff or ridge. The rock fragments that form talus may be rock waste, slide rock, or pieces broken by frost action. Term widely used to mean the rock debris itself. Slopes are often cone shaped and formed chiefly by gravitational induced falling, rolling, or sliding.

Topple: Form of landsliding characterized by the forward rotation out of the slope of a mass of soil or rock about a point or axis below the center of gravity of the displaced mass. The definitive characteristic is that the block of moving material tips outward beginning at the top and begins transport down slope with the top of the block leading, or tumbles end over end down the slope.

Translational sliding: Mode of slide in which the moving mass separates from the slope on a plane that is nearly parallel to the slope surface. The toe of the moving mass is often pushed beyond the end of the detachment surface where it moves over bedrock forming lobe shaped toes. Commonly more shallow than rotational slides.

Trigger: An external stimulus such as intense rainfall, earthquake shaking, volcanic eruption, storm waves, or rapid stream erosion, that causes a near immediate response in the form of a landslide by rapidly increasing the stresses or by reducing the strength of the slope materials. Immediate cause.

Velocity: The rate at which a movement is displacing. Velocity is a parameter whose destructive significance requires independent definition.

Very wet: Contains enough water to flow as a liquid under low gradients.

Vulnerability: the susceptibility or exposure to injury or loss from a hazard.

Weathering: Changes that take place in rocks and minerals at or near the surface of the Earth in response to physical, chemical, and biological changes. Weathering agents include processes, such as the chemical action of air and rainwater, plants and bacteria, as well as the mechanical action of changes of temperature. The destructive processes by which earth and rock at or near the surface are changed in color, texture, composition, firmness, or form, with little or no transport of the loosened or altered material. It produces an *in situ* mantle of waste and prepares sediments for transportation. Most weathering occurs at or near the surface, but it may take place at considerable depths.

Wet: Contains enough water to behave in part as a liquid, has water flowing from it, or supports significant bodies of standing water.

Widening landslide: Mass movement in which the surface of rupture is extending at one or both lateral margins.

APPENDIX F

BIBLIOGRAPHIES

F.1.0 MAP BIBLIOGRAPHY

Agard, S.S., Colton, R.B., and Kanizay, S.P., 1987, Landslide deposits in the Lodge Grass 30'x60' quadrangle, Montana and Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map, MF-1928, scale 1:100,000.

Bergantino, R.N., 1980, Geologic map of the Hardin 1X2-degree quadrangle, southeastern Montana: Montana Bureau of Mines and Geology, Montana Atlas 2-A, scale 1:100,000.

_____, 1980, Geologic map of the Ekalaka 1x2-degree quadrangle, southeastern Montana: Montana Bureau of Mines and Geology, Montana Atlas 1-A, scale 1:100,000.

Blackstone, D.L., Jr., 1981, Preliminary geologic map of the Deep Creek SW 7.5-minute quadrangle, Big Horn County, Montana: Montana Bureau of Mines and Geology, Open-File Report 62, 1:24,000.

_____. 1981, Preliminary geologic map of the Deep Creek SE 7.5-minute quadrangle, Big Horn County, Montana: Montana Bureau of Mines and Geology, Open-File Report 63, 1:24,000.

_____, 1981, Preliminary geologic map of the Castle Rocks 7.5-minute quadrangle, Big Horn County, Montana: Montana Bureau of Mines and Geology, Open-File Report 64, 1:24,000.

_____, 1981, Preliminary geologic map of the Big Ice Cave 7.5-minute quadrangle, Big Horn and Carbon Counties, Montana: Montana Bureau of Mines and Geology, Open-File Report 65, 1:24,000.

_____, 1981, Preliminary geologic map of the Red Pryor Mountain 7.5-minute quadrangle, Carbon County, Montana: Montana Bureau of Mines and Geology, Open-File Report 68, 1:24,000.

_____, 1981, Preliminary geologic map of the Mystery Cave 7.5-minute quadrangle, Big Horn and Carbon Counties, Montana: Montana Bureau of Mines and Geology, Open-File Report 70, 1:24,000.

_____, 1981, Preliminary geologic map of the Indian Spring 7.5-minute quadrangle, Big Horn and Carbon Counties, Montana: Montana Bureau of Mines and Geology, Open-File Report 71, 1:24,000.

Colton, R.B., 1955, Geology of the Wolf Point quadrangle: U.S. Geological Survey, Geologic Quadrangle Map GQ 67, 1 sheet, scale 1:62,500.

_____, 1963, Geologic map of the Tule Valley quadrangle, Roosevelt County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-371, scale 1:62,500.

_____, 1963, Geologic map of the Brockton quadrangle, Roosevelt and Richland Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-362, scale 1:62,500.

_____, 1963, Geologic map of the Chelsea quadrangle, Roosevelt and McCone Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-363, scale 62,500.

_____, 1963, Geologic map of the Custer quadrangle, Roosevelt County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-364, scale 1:62,500.

_____, 1963, Geologic map of the Hay Creek quadrangle, Roosevelt county, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-365, scale 1:62,500.

_____, 1963, Geologic map of the Oswego Quadrangle, Valley, Roosevelt, and McCone Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-366, scale 1:62,500.

_____, 1963, Geologic map of the Poplar quadrangle, Roosevelt, Richland and McCone Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-367, scale 1:62,500.

_____, 1963, Geologic map of the Spring Creek quadrangle, Valley County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-369, scale 1:62,500.

_____, 1963, Geologic map of Todd Lakes quadrangle, Valley and Roosevelt County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-370, scale 1:62,500.

_____, 1964, Geologic map of the south half of the Baylor, Larslan, West Fork, Police Creek, Kahle, and Lundville quadrangles, Valley, Roosevelt, and Daniels Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-361, scale 1:62,500.

_____, 1979, Geologic map of the Bainville SE quadrangle, Roosevelt and Richland Counties, Montana and Williams County, North Dakota: U.S. Geological Survey Miscellaneous Field Studies Map MF-1112, scale 1:24,000.

_____, 1982, Geologic map of the Twomile Creek quadrangle, Richland and Roosevelt Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1413, scale 1:24,000.

Colton, R.B., Klockenbrink, J.L., and Heffern, E.L., 1983, Photogeologic and reconnaissance geologic map to the Hathaway quadrangle, Custer and Rosebud Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1663, scale 1:24,000.

Colton, R.B., Klockenbrink, J.L., Heffern, E.L., and Bierback, P. R., 1987, Photogeologic and reconnaissance geologic quadrangle map of the Miller Creek NW quadrangle, Custer and Rosebud Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2014, scale 1:24,000.

Colton, R.B., Klockenbrink, J.L., Grout, M.A., Heffern, E.L., and Bierback, P. R., 1987, Photogeologic and reconnaissance geologic map of the Black Coulee quadrangle map of the Black Coulee quadrangle, Rosebud County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-2011, scale 1:24,000.

Colton, R.B., Klockenbrink, J.L., Durst, S.L., Grout, M.A., Heffern, E.L., and Bierback, P. R., 1987, Photogeologic and reconnaissance geologic quadrangle map of the Miller Creek quadrangle, Custer and Rosebud Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2013, scale 1:24,000.

Colton, R.S., Klockenbrink, J.L., Durst, S.L., Heffern, E.L., and Bierback, P. R., 1987, Photogeologic and reconnaissance geologic quadrangle map of the Moon Creek School quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-2015, scale 1:24,000.

Colton, R.B., Whitaker, S.T., Ehler, W.C., Fuller H.K., 1978, Preliminary Photogeologic map of the Four Buttes, Scobey, and Flaxville quadrangles, Daniels County, Montana: U.S. Geological Survey Geological Open-File Report 78-898, 1 sheet, scale 1:50,000.

Cruden, D.M. and Varnes, D.J., 1996, Chapter 3, Landslide types and processes, *in* Turner, A. K., and Schuster, R. L. S., *eds*., Landslides—Investigation and mitigation: Transportation Research Board, National Research Council, Special Report 247, National Academy Press, 673 p.

Denson, N.M., Bachman, G.O., Zeller, H.D., Gill, J.R., Moore, G.W., and Melin, R.E., 1955, Uraniferous coal beds in parts of North Dakota, South Dakota, and Montana: U.S. Geological Survey Coal Investigations Map, C-33, scale: 1 inch=1 mile.

Derkey, P.D. and Bartholomew, M.J., 1988, Geologic map of the Ramsay quadrangle, Montana: Montana Bureau of Mines and Geology, Geologic Map GM-47, scale 1:24,000.

du Bray, E.A., Elliott, J.E., Wilson, A.B., Van Gosen, B.S., and Rosenberg, L.A., 1993, Geologic map of the Big Timber stock and vicinity, southern Crazy Mountains, Sweet Grass and Park Counties, South-Central Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-2253, scale 1:24,000.

Elliott, J.E., Geologic map of the southwest part of the Cooke City quadrangle, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Map, I-1084, scale 1:24,000.

Ellis, M.S., and Colton, R.B., 1994, Geologic map of the Powder River Basin and surrounding area, Wyoming, Montana, South Dakota, North Dakota, and Nebraska: U.S. Geological Survey Miscellaneous Investigations Map I-2298, scale 1:500,000.

Gardner, L.S., 1959, Geology of the Lewistown area, Fergus County, Montana: U.S. Geological Survey Oil and Gas Investigations Map OM-199, scale 1:63,360.

Gualtieri, J.L., 1975, Preliminary unedited geologic map of the Confederate Gulch area, Broadwater and Meagher Counties, Montana: U.S. Geological Survey Geological Open-File Report 75-211.

Gwinn, V.E., 1961, Geology of the Drummond area, central-western Montana: Montana Bureau of Mines and Geology, Geologic Map 4, 1 sheet.

Hadley, J.B., 1969, Geologic map of the Cameron quadrangle, Madison County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-813, scale 1:62,500.

Harrison, J.E., Griggs, A.B., and Wells, J.D., 1986, Geologic and structure maps of the Wallace 1 x 2-degree quadrangle, Montana and Idaho: Montana Bureau of Mines and Geology, Montana Atlas 4-A, 2 sheets, scale 1:250,000.

Hinrichs, E.N., 1984, Surficial geologic map of the Sheridan 30'x60' quadrangle, Wyoming and Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1693, scale 1:100,000.

Karasevich, L.P., 1981, Geologic map of the northern Ruby Range, Madison County, Montana: Montana Bureau of Mines and Geology, Geologic Map, GM 25, 1 sheet, scale 1:24,000.

Keefer, W.R., Geologic map of the west half of the Neihard 15-minute quadrangle, central Montana: U.S. Geological Survey Miscellaneous Investigations Map I- 726, scale 1:62,500.

Knechtel, M.M., and Patterson, S.H., 1956, Bentonite deposits of the northern Black Hills District, Montana, Wyoming, and South Dakota: U.S. Geological Survey Mineral Investigations Field Studies Map MF 36, 2 sheets, 1:48,000.

Lange, I.M., and Zehner, R.E., 1992, Geologic map of the Hog Heaven Volcanic Field, northwestern Montana: Montana Bureau of Mines and Geology, Geologic Map GM-53, 6 p., scale 1:100,000.

Lemke, R.W., 1977, Geologic map of the Great Falls quadrangle, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1414, scale 1:62,500.

Lemke, R.W., and Maughan, E.K., 1977, Engineering geology of the city of Great Falls and vicinity, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1025, scale 1:24,000.

Lewis, S.E., 1990, Geologic map of the Dickie Peak quadrangle, Deer Lodge and Silver Bow Counties, Montana: Montana Bureau of Mines and Geology, Geologic Map, GM-51, 6 p., scale 1:24,000.

Lindsey, D.A., Hopkins, D.M., Mosier, E.L., and Antweiler, J.C., 1980, Reconnaissance map of the Big Snowies Wilderness and contiguous rare II study areas, Fergus, Golden Valley, and Wheatland Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map, MF-1243-D, scale 1:100,000.

Lindvall, R.M., 1953, Geologic map of the Eagleton quadrangle, Montana: U.S. Geological Survey Geologic Quadrangle Map, GQ-29, scale 1:62,500.

Luft, S.J., and Colton, R.B, 1984, Photogeologic and reconnaissance geologic map of the Paddy Fay Creek quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1683, scale 1:24,000.

_____, 1984, Photogeologic and reconnaissance geologic map of the Montague Butte quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1704, scale 1:24,000.

Luft, S.J., Colton, R.B., and Cormier, G.P., 1984, Photogeologic and reconnaissance geologic map of the Big Hill quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1679, scale 1:24,000.

Luft, S.J., Colton, R.B., and Heffern, E.L., 1984, Photogeologic and reconnaissance geologic map of the Hogan Creek quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1685, scale 1:24,000.

_____, 1984, Photogeologic and reconnaissance geologic map of the Buck Mountain quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1703, scale 1:24,000.

_____, 1984, Photogeologic and reconnaissance geologic map of the Knob quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1702, scale 1:24,000.

_____, 1984, Photogeologic and reconnaissance geologic map of the Locate SW quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1700, Scale 1:24,000.

_____, 1984, Photogeologic and reconnaissance geologic map of the Whitney Creek quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1707, scale 1:24,000.

Luft, S.J., Colton, R.B., Heffern, E.L., and Cormier, G.P., 1983, Photogeologic and reconnaissance geologic map of the Locate quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1513, scale 1:24,000.

Luft, S.J., Cormier, G.P., Heffern, E.L., and Colton, R.B., 1984, Photogeologic and reconnaissance geologic map of the Government Hill quadrangle, Custer County, Montana: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1705, scale 1:24,000.

MacLachlan, Campbell, W.L., Klienkopf, M.D., and Larson, C.E., 1981, Geology and resources appraisal of the Square Butte area, Montana: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1370, 1 sheet, scale 1:24,000.

Mapel, W.J., 1978, Preliminary geologic map of the Crow Reserve area, Big Horn County, Montana: U.S. Geological Survey Geological Open-File Report 78-998, 1 sheet.

Mapel, W.J., Robinson, C.S., and Theobald, P.K., 1959, Geologic and structure contour map of the northern and western flanks of the Black Hills, Wyoming, Montana, and South Dakota: U.S. Geological Survey Oil and Gas Investigations Map OM-191, 2 sheets, scale 1:96,000.

McGrew, L.W., 1977, Geologic map of the Sixteen quadrangle, Gallatin and Meagher Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1383, scale 1:24,000.

_____, 1977, Geologic map of the Sixteen NE quadrangle, Meagher, Gallatin, and Park Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1384, scale 1:24,000.

McLellan, M.W., and Olive, W.W., 1991, Geologic map of the Samuelson Ranch quadrangle, Powder River County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-2141, scale 1:24,000.

_____, 1991, Geologic map of the Elk Ridge Quadrangle, Powder River County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-2140, scale 1:24,000.

M'Gonigle, J.W., Geologic map of the Medicine Lodge Peak quadrangle, Beaverhead County Southwest Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1724, scale 1:24,000.

Mudge, M.R., 1966, Geologic map of Patricks Basin quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-453, scale 1:24,000.

_____, 1966, Geologic map of the Pretty Prairie quadrangle, Lewis and Clark County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-454, scale 1:24,000.

_____, 1966, Geologic map of the Glenn Creek quadrangle, Lewis and Clark and Teton Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-499, scale 1:24,000.

_____, 1967, Geologic map of the Arsenic Peak quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-597, scale 1:24,000.

_____,1967, Surficial geologic map of the Sawtooth Ridge quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-610, scale 1:24,000.

_____, 1972, Surficial geologic map of the Castle Reef quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-991, scale 1:100,000.

Mudge, M.R., Earhart, M.R., Whipple, J.W., and Harrison, J.E., 1983, Geologic maps of the Choteau 1 x 2-degree quadrangle, northwestern Montana: Montana Bureau of Mines and Geology, Montana Atlas 3-A, scale 1:100,000.

Page, N.K., and Nokleberg, W.J., 1974, Geologic map of the Stillwater Complex, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-797, 5 sheets, scale 1:12,000.

Page, M.J., Simons, F.S., and Dohrenwend, J.C., 1973, Reconnaissance geologic map of the Mount Douglas quadrangle, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-488, scale 1:62.500.

_____, 1973, Reconnaissance geologic map of the Mount Wood quadrangle, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-491, scale 1:62,500.

Page, W.R., Dixon, G.L. and Workman, J.B., 1998, The Blue Diamond Landslide: A Tertiary breccia deposit in the Las Vegas area, Clark County, Nevada: The Geological Society of America Map and Chart Series MCH083, scale 1:24,000.

Pierce, K.L., 1973, Surficial geologic map of the Mount Holmes quadrangle and parts of the Tepee Creek, Crown Butte, and Miner quadrangles, Yellowstone, National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-640, scale 1:62,500.

_____, 1973, Surficial geologic map of the Mammoth quadrangle and part of the Gardiner quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-641.

_____, 1974, Surficial geologic map of the Abiathar Peak and parts of adjacent quadrangles, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-646, scale 1:62,500.

_____, 1974, Surficial geologic map to the Tower Junction quadrangle and part of the Mount Wallace quadrangle, Yellowstone National Park, Wyoming and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-647, scale 1:62,500.

Radbruch-Hall, D.H., Colton, R.B., Davis, W.E., Skipp, B.A., Lucchitta, I., and Varnes, D.J., 1976, Preliminary landslide overview map of the conterminous United States: U.S. Geological Survey Miscellaneous Field Studies Map, MF-771, scale 1:7,500,00.

Reheis, M.C., and Williams, V.S., 1984, Surficial geologic map of the Recluse 30' x 60' quadrangle, Wyoming and Montana: U.S. Geological Survey Coal Investigations Map C-81-F, scale 1:100,000.

Richards, P.W., and Rogers, C.P., Jr., 1951, Geology of the Harden area, Big Horn and Yellowstone Counties, Montana: U.S. Geological Survey Oil and Gas Investigations Map OM-111, scale 1 inch=1 mile, 2 sheets.

Roberts, A. E., 1964, Geologic map of the Bozeman Pass quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-399, scale 1:24,000.

_____, 1964, Geology of the Brisbane quadrangle, Montana: U.S. Geologic Survey Geologic Quadrangle Map GQ-256, scale 1:24,000.

_____, 1964, Geologic map of the Fort Ellis quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-397, scale 1:24,000.

_____, 1964, Geologic map of the Maxie Ridge quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-396, scale 1:24,000.

_____, 1964, Geologic map of the Mystic Lake quadrangle, Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-398, scale 1:24,000.

_____, 1964, Geology of the Chimney Rock quadrangle, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-257, scale 1:24,000.

Robinson, G.D., 1967, Geologic map of the Toston quadrangle southwestern Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-486, 2 sheets, 1:24,000.

Robinson, G.D., McCallum, M.E., and Hays, W.H., 1969, Geologic map of the Upper Holter Lake quadrangle, Lewis and Clark County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-840, scale 1:24,000.

Schmidt, R.G., 1972, Geologic map of the Wolf Creek quadrangle, Lewis and Clark County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-974, scale 1:24,000.

_____, 1972, Geologic map of the Coburn Mountain quadrangle, Lewis and Clark and Cascade Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-975, scale 1:24,000.

_____, 1972, Geologic map of the Comb Rock quadrangle, Lewis and Clark County, Montana: U.S. Geological Survey Geological Quadrangle Map GG-976, scale 1:24.000.

____, 1977, Geologic map of the Craig quadrangle, Lewis and Clark and Cascade Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1411, scale 1:24,000.

Schmidt, R.G., and Strong, C.P., Jr., 1972, Geologic map of the Roberts Mountain quadrangle, Lewis and Clark County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-977, scale 1:24,000.

Skipp, B., 1977, Geologic map and cross section of the Wallrock quadrangle, Gallatin and Park Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1402, scale 1:24,000.

Skipp, B., and Hepp, M., 1968, Geologic map of the Hatfield Mountain quadrangle, Gallatin County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-729, scale 1:24,000.

Skipp, B., and McMannis, W.J., 1971, Geologic map of the Sedan quadrangle, Gallatin and Park Counties, Montana: U.S. Geological Survey Geological Open-File Report 71-264, 2 sheets, scale 1:48,000.

Skipp, B., and Peterson, A., 1965, Geologic map of Maudlow quadrangle southwestern Montana: U.S. Geological Survey Miscellaneous Investigations Map I-452, 2 sheets, 1:24,000.

Skipp, B., Prostka, H.J., and Schleicher, D.L., 1979, Preliminary geologic map of the Edie Ranch quadrangle, Clark County, Idaho, and Beaverhead County, Montana: U.S. Geological Survey Geological Open-File Report 79-845, 2 sheets, scale 1:48,000.

Smedes, H.W., Klepper, M.R., Pinckney, D.M., Becraft, G.E., and Ruppel, E.T., 1962, Preliminary map of the Elk Park quadrangle, Jefferson and Silver Bow Counties, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map, MF-246, scale 1:48,000.

Soward, K.S., 1975, Geologic map of the Rocky Reef quadrangle, Cascade County, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1240, scale 1:24,000.

_____, 1975, Geologic map of the Hardy quadrangle, Cascade and Lewis and Clark Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-1241, scale 1:24,000.

Stickney, M.C., 1987, Quaternary geologic map of the Helena valley, Montana: Montana Bureau of Mines and Geology, Geologic Map GM 46, 1 sheet, scale 1:50,000.

Tysdal, R.G., 1976, Geologic map of the northern part of Ruby Range, Madison County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-951, scale 1:24,000.

Tysdal, R.G., Dyman, T.S., and Lewis, S.E., 1994, Geologic map of Cretaceous strata between Birch Creek and Brownes Creek, eastern flank of Pioneer Mountains, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-2434, scale 1:24,000.

Vuke, S.M., Berg, R.B., Colton, R.B., and O'Brien, H.E., 1995, Geologic map of the Belt 30' x 60' quadrangle, central Montana: Montana Bureau of Mines and Geology, Geologic Map GM-54, scale 1:100,000.

Vuke-Foster, S.M., Colton, R.B., Stickney, M.C., Wilde, E.M., Robocker, J.E., and Christensen, K.C., 1986, Geology of the Baker and Wibaux 30X60-minute quadrangles, eastern Montana and adjacent North Dakota: Montana Bureau of Mines and Geology, Geologic Map, GM-41, scale 1:100,000.

Wallace C.A., and Klepper, M.R., 1976, Preliminary reconnaissance geologic map of the Cleveland Mountain and north half of the Ravenna quadrangles (1:48,000), western Montana: U.S. Geological Survey Open-File Report 76-527, 1 sheet, scale 1:48,000.

Wallace, C.A., Klepper, M.R., and Scarborough, D.M., 1977, Preliminary reconnaissance geologic maps of the Garnet Range, western Montana: U.S. Geological Survey Open-File Report 77-529.

Wallace, C.A., Lidke, D.J., Elliott, J.E., Antweiler, J.C., Campbell, J.H., Hassemer, J.H., Hanna, W.F., Banister, D.P., and Close, T.J., 1984, Mineral resource potential of the Sapphire Wilderness Study area and contiguous roadless areas, Granite and Ravalli Counties, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1469-B, 32 p., 2 sheets, scale 1:50,000.

Wallace, C.A., Schmidt, R.G., Lidke, D.J., Waters, M.R., Elliott, J.E., French, A.B., Whipple, J.W., Zarske, S.E., Blaskowski, Heise, B.A., Yeoman, R.A., O'Neill, Lopez, D.A., Robinson, G.D., Klepper, M.R., 1986, Preliminary geologic map of the Butte 1X2-degree quadrangle, western Montana: U.S. Geological Survey Open-File Report OF-86-292, 16 p., 1 slide, 1 plate, scale 1:100,000.

Wanek, A.A., 1963, Geologic map of the Cooney Reservoir quadrangle, Carbon and Stillwater Counties, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-265, scale 1:24,000.

_____, 1963, Geologic map of the Rapids quadrangle, Carbon and Stillwater Counties, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-270, scale 1:24,000.

Witkind, I.J., 1972, Geologic Map of the Henrys Lake quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-781-A,B,C,F, 2 sheets, scale 1:62,500.

_____, 1971, Geologic map of the Barker quadrangle, Judith Basin and Cascade Counties, Montana: U.S. Geological Survey Geological Quadrangle Map GQ-898, 1:62,500.

_____, 1975, Geology of a strip along the Centennial Fault, southwestern Montana and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-890, scale 1:62,500.

_____, 1976, Geologic map of the southern part of the Upper Red Rock Lake quadrangle, southwestern Montana and adjacent Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-943, scale 1:62,500.

Witkind, I.J., Boyles, J.M., and Patterson, P.E., 1979, Generalized slope map of the Big-Fork--Avon environmental study area, Flathead, Lake, Missoula, and Powell Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1130, 1 sheet, scale 1:125,000.

Witkind I.J., and Prostka, H.,J., 1980, Geologic map of the southern part of the lower Red Rock Lake quadrangle, Beaverhead and Madison Counties, Montana, and Clark County, Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-1216, scale 1:62,500.

Witkind, I.J., and Weber, W.M., 1982, Reconnaissance geologic map of the Big Fork-Avon Environmental study area, Flathead, Lake, Lewis and Clark, Missoula, and Powell Counties, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1380, scale 1:125,000.

Zeller, H.D., 1963, Geologic map of the Roberts quadrangle, Carbon County, Montana: U.S. Geological Survey Mineral Investigations Field Studies Map MF-266, scale 1:24,000.

F.2.0 TEXT BIBLIOGRAPHY

Alden, W.C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geological Survey Professional Paper 174, 133 p., 51 plates.

Alt, D.C. and Hyndman, D.W., 1974, An interpretation of geology in the Glacier Park area—A Descriptive road log *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 233-238.

_____, 1986, Roadside geology of Montana: Mountain Press Publishing Company, 427 p.

Anonymous, 1978, Potential rockfall at Billings, Montana [abstract]: U.S. Geological Survey, Professional Paper 1100, p.292.

Beaty, C.B., 1961, Boulder deposit in Flint Creek valley, western Montana: Geological Society of America Bulletin, v.72, p. 1015-1020.

Becraft, G.E., Calkins, J.A., Pattee, E.C., Weldin, R.D., and Roche, J.M., 1966, Studies related to wilderness: Mineral resources of the Spanish Peaks primitive area, Montana: U.S. Geological Survey Bulletin 1230-B, 45 p., 2 plates.

Berg, R.B., 1977, Reconnaissance geology of the southernmost Ravalli County, Montana: Montana Bureau of Mines and Geology Memoir 44, 39 p., 1 plate.

Blackstone, D.L., Jr., 1975, Geology of the East Pryor Mountain quadrangle, Carbon County, Montana: Montana Bureau of Mines and Geology, Special Publication 69, 13 p., 1 sheet.

Bradley, C.C., and Montagne, J., 1972, Snow and avalanche research in Montana *in* Crazy Mountains Basin: Montana Geological Society Annual Field Conference Guidebook 21, p. 175-180.

Butler, D.R., 1976, Aerial-photo interpretation of mass-wasting deposits, Glacier National Park, Montana: Abstracts of the Fourth biennial meeting of the American Quaternary Association, National Conference Abstracts, v. 4, p. 127.

_____, 1980 Terminal elevations of snow avalanche paths, Glacier National Park, Montana: Northwest Geology, v. 9, p. 59-64.

_____, 1983, Observations of historic high magnitude mass movements, Glacier National Park, Montana: The Mountain Geologist, v. 20, no. 2, p. 59-62.

_____, 1989, Glacial hazards in Glacier National Park, Montana: Physical Geography v. 10, no. 1, p. 53-71.

Campbell, A.B., 1960, Geology and mineral deposits of the St. Regis-Superior area, Mineral County, Montana: U.S., Geological Survey Bulletin 1082-I, p. 545-612, 6 plates.

Campbell, M.R., 1914, Glacier National Park: A popular guide to its geology and scenery: U.S. Geological Survey Bulletin 600, 54 p., 13 plates.

Campbell, M.P., 1978, Caves of Montana: Montana Bureau of Mines and Geology, Bulletin 105, 169 p.

Colton, R.B., 1962, Contributions to general geology--Geology of the Otter Creek Quadrangle Montana: U.S. Geological Survey U.S. Geological Survey Bulletin 1111-G, p. 237-288, 5 plates.

Condit, D.D., 1919, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U.S. Geological Survey Bulletin 711-B, p. 40, 1 plate.

Cox, W.E., 1977, The Goldcreek, Montana, landslide: 15th Annual Engineering Geology, Soils Engineering Symposium, Proceedings, p. 149-159.

Czamanske, G.K., and Zientek, M.L., eds., 1985, The Stillwater Complex, Montana: Geology and Guide: Montana Bureau of Mines and Geology, Special Publication 92, 396 p., 4 sheets.

Davis, L.G., Montagne, C., Montagne, J., Nielsen G., and Pierce, K., 1974, Annual field trip; Hebgen Lake area to Bozeman, Montana via Highway 191; Itinerary and road log for September 7, 1974, Excursion to Schmidt Site, Three Forks, Montana, Sept 8, 1974: Friends of the Pleistocene, Rocky Mountain Section, 12 p.

Davis, W.M., 1910, Origin of Cliff Lake, Montana; discussion: Geological Society of America Bulletin, 21, p. 764.

Derkey, P.D., Abercrombie, F.N., Vuke, S.M., and Daniel, J.A., 1985, Geology and oil shale resources of the Heath Formation, Fergus County, Montana: Montana Bureau of Mines and Geology, Memoir 57, 100 p., 2 sheets.

Donahue, J.J., 1985, Topographic inversion of badland buttes in Montana: Geological Society of America Bulletin, v. 96, p. 911-917.

Dupree, H.K., and Taucher, G.J., 1974, Bighorn Reservoir landslides, south-central Montana *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 59-63.

Dupree, H.K., Taucher, G.J., and Voight, B., 1979, Bighorn Reservoir slides, Montana, U.S.A. *in* Voight, B., ed., Rockslides and avalanches; Vol. 2. Engineering sites: Elsevier Scientific Publishing Company, Amsterdam Netherlands, p. 247-267.

Dustin, J.D., 1941, Fort Peck slide: American Society of Civil Engineers, Proceedings—Discussion, v. 67, no. 4, p. 723-726.

Earll, F.N., 1972, Mines and mineral deposits of the southern Flint Creek Range, Montana: Montana Bureau of Mines and Geology, Bulletin 84, 54 p., 3 plates.

Elliott, J.E., The Geology of the Cooke City area, Montana and Wyoming *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of The International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 102-107.

Fahlquist, F.E., 1941, Fort Peck slide--Discussion: American Society of Civil Engineers, Proceedings, v. 67, no. 7, p. 1242-1244.

Fields, R.W., 1972, Geology of the Tertiary intermontane basins of western Montana: Geological Society of America Abstracts with programs for 1972, p. 376.

Fleming, R.W., Lemke, R.W., and Maughan, E.K., 1983, Twenty-eight year history of a landslide Northeast of Great Falls, Montana: Bulletin of the Association of Engineering Geologists, v. 20. no. 4, p. 373-385.

Fox, R.D., 1966, Geology and ground-water resources of the Cascade-Ulm area, Montana: Montana Bureau of Mines and Geology, Bulletin 52, p.64, 1 plate.

Gagnon, J.M. R., 1968, Slope stability at Lac Jeannine: Canadian Mining and Metallurgy Bulletin, v. 61, no. 678, p. 1166-1174.

Gallatin County Study Team, 1974, The Gallatin area: A summary report: Montana State University, Bozeman, Extension Service Bulletin, 36 p.

Galster, R.W., 1974, Engineering geology at the Flathead Tunnel, Libby Project, Montana *in* Voight, B., ed., Rock mechanics, the American Northwest: Pennsylvania State University, University Park, p. 217-219.

Gassaway, J.S., Toth, M.I., Bankey, V. Kleinkopf, M.D., and Causey J.D., Mineral resources of the Terry Badlands Wilderness study area, Prairie and Custer Counties, Montana: U.S. Geological Survey Bulletin 1722-B, 12 P., 1 Plate, scale 1:50,000.

Gerig, W., Ryan, A.J., and Gilboy, G., 1941, Fort Peck slide: American Society of Civil Engineers, Proceedings—Discussion, v. 67, no. 5, p. 891-898.

Gill, J.R., 1962, Tertiary landslides, northwestern South Dakota and southwestern Montana: Geological Society of America Bulletin, v. 73, p.725-736, 1 plate.

Good, J.E., 1965, Prehistoric landslide in Yankee Jim Canyon, Park County, Montana [abstract]: Geological Society of America Special Paper 82, p. 327-328.

Good, J.M., 1982, The Yankee Jim Canyon landslide--Park County, Montana *in* Geology of Yellowstone Park area: Wyoming Geological Association 33rd Annual Field Conference Guidebook, p. 53-54.

Goolsby, J.E., East rock glacier of Lone Mountain, Madison County, Montana: Geological Society of America Abstracts with programs for 1972, v.4, no., 6, p. 377-378.

Griffith, E.P., 1982, Geologic constraint; the basis for land use planning in the Story Hills, Gallatin, Montana: Geological Society of America, Rocky Mountain Section, 35th annual meeting, Abstracts with programs, v. 14, no. 6., p. 313.

Gucwa, P.R., and Kehle, R.O., 1978, Bearpaw Mountains rockslide, Montana, U.S.A., *in* Voight, B., ed., Rockslides and avalanches, Vol. 1, Natural phenomena: Elsevier Scientific Publishing Company, Amsterdam, Netherlands, Developments in geotechnical engineering collection, Vol. 14A, p. 393-421.

Hadley, J.B., 1959, The Madison Canyon landslide [Montana]: Geotimes, v. 4., issue 3, p. 14-17.

_____, 1960, The Madison landslide [Montana] *in* West Yellowstone; earthquake area: Billing Geological Society 11th Annual Field Conference Guidebook, September 1960, p. 45-48.

_____, 1964, Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959, *in* The Hebgen Lake, Montana, earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435, p. 107-138.

_____, 1974, Madison Canyon (1959) landslide *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 134-137.

_____, 1974, Madison Canyon (1959) landslide *in* Voight, B., etal, ed., Rock Mechanics, the American Northwest: Pennsylvania State University, University Park, p. 134-137.

_____, 1978, Madison Canyon rockslide, Montana, U.S.A. *in* Voight, B., ed., Rockslides and avalanches, Vol. 1, Natural phenomena: Elsevier Scientific Publishing Company, Amsterdam, Netherlands, Developments in geotechnical engineering collection, Vol. 14A, p.167-180.

Hall, R.D., Heiny, J.S., and Ward, P.N., 1982, Glacial geology of Cataract Creek and North Willow Creek valleys, in the area west of Pony, Montana, Tobacco Root Range: Annual Tobacco Root Geological Society, 1980 field conference guidebook, p. 58-78.

Hamel, J.V., and Spencer, G.S., 1984, Powerhouse slope behavior, Fort Peck Dam, Montana *in* Prakash, S., ed., International conference on case histories in geotechnical engineering, Vol. 2: University of Missouri, Rolla, p. 541-551.

Harrison, A., 1974, Madison Canyon slide mass modification by the U.S. Corps of Engineers *in* Voight, B., and Voight, M.A., eds., Rock Mechanics—The American Northwest: University Park: Experimental Station, College of Earth and Mineral Sciences, Pennsylvania State University, p. 138-141.

Hayes, G.S., 1982, Geologic stability of Mystic Lake Dam, Gallatin County, Montana: Geological Society of America, Rocky Mountain Section, 35th annual meeting, abstracts with programs, v. 14, no. 6, p. 315.

Hearn, B.C., Jr., Pecora, W.T., Swadley, W.C., 1964, Contributions to general geology: Geology of the Rattlesnake quadrangle Bearpaw Mountains Blaine County, Montana: U.S. Geological Survey Bulletin 1181-B, 66 p., 1 plate.

Helburn, N., 1960, Southwestern Montana earthquake and landslide: Geographical Review, V. 50, no. 1, p. 109-111.

Henton, J.M., 1907, An interesting study in geology (landslip in Montana): Mining World, v. 27, p. 975.

Hettinger, R.D., Bankey, V., and Causey, D.J., 1987, Mineral resources of the Burnt Lodge Wilderness study area, Phillips and Valley Counties, Montana: U.S. Geological Survey Bulletin 1722-A, 16 p., 1 plate, scale 1:24,000.

Hettinger, R.D., Bankey, V., and Miller, M.S., 1988, Mineral resources of the Seven Blackfoot Wilderness study area, Garfield County, Montana: U.S. Geological Survey Bulletin 1722-D, 22 p., 2 plates.

Hyndman, D.W., and Brown, J., 1998, Blackfoot River landslide, Montana *in* Geological Society of America, 1998 annual meeting Abstracts with programs: Geological Society of America, Boulder Co., vol. 30, no. 7, p. 179.

Johns, W.M., 1974, Belt (Precambrian) sedimentary rocks in northwest Montana *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 208-212.

_____, 1974, Roadlog—Kalispell-Libby Dam—Rocky Mountain trench *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington.

Johnson, C.V., 1960, Madison slide subsurface exploration and observations, Appendix 10 *in* U.S. Corps of Engineer, Madison River slide: U.S. Corps of Engineers, V. 2, Appendixes, p. X-1-X-10.

Johnson, W.D., Jr., and Smith, H.R., 1964, Geology of the Winnett-Mosby area, Petroleum, Garfield, Rosebud, and Fergus Counties, Montana: U.S. Geological Survey, Bulletin 1149, 91 p., 3 plates.

Jones, W.V., and Stilley, A., 1986, Geotechnical design considerations for road construction of an active talus slope *in* Proceedings of the 37th annual highway geology symposium—Geotechnical aspects of construction in mountainous terrain: Montana Department of Highways and Montana Division-Federal Highway Administration, p. 11-26.

Klepper, M.R., Weeks, R.A., and Ruppel, E.T., 1957, Geology of the southern Elkhorn Mountains Jefferson and Broadwater Counties, Montana: U.S. Geological Survey Professional Paper 292, 82 p., 8 plates.

Klepper, M.R., Ruppel, E.T., Freeman, V.L., Weeks, R.A., 1971, Geology and mineral deposits, east flank of the Elkhorn Mountains, Broadwater County, Montana: U.S. Geological Survey Professional Paper 665, 66 p., 4 plates.

Lageson, D.R., Kellogg, K.S., and O'Neill, J.M., 1997, Potential for catastrophic landslide failure of northwest flank of Jumbo Mountain, Spanish Peaks Wilderness, Montana *in* Northwest Geology—The edge of the Crazies: Geology where the mountains meet the prairie: Tobacco Root Society 22nd Annual Field Conference with the Montana Geological Society, p. 13-18.

Lindsey, D.A., 1982, Geologic map and discussion of selected mineral resources of the north and south Moccasin Mountains, Fergus County, Montana:` U.S. Geological Survey Miscellaneous Investigations Map I-1362, scale 1:24,000.

Locke, W.W., Berg, R.B., and Lonn, J.D., 1997, Geologic float log to the middle Yellowstone River (between Gardiner and Emigrant Point of Rocks), Montana: Montana Geological Society Field Conference, 21 p.

Lopez, D.A., 1995, Geology of the Sweet Grass Hills, north-central Montana: Montana Bureau of Mines and Geology, Memoir 68, 35 p., 1 plate.

McKee, B., 1974, The northwestern part of the Columbia Plateau *in* Voight, B., and Voight, M.A., eds., Rock Mechanics—The American Northwest: University Park Experimental Station, College of Earth and Mineral Sciences, Pennsylvania State University, p. 241-246.

McMannis, W.J., and Chadwick, R.A., 1964, Geology of the Garnet Mountain quadrangle, Gallatin County, Montana: Montana Bureau of Mines and Geology, Bulletin 43, 47 p., 1 sheet.

McMannis, W.J., and Kiel, D.L., 1982, West Yellowstone to Madison Canyon Slide-via Reynolds Pass, via U.S. Highway 20-191, State Highway 87 and U.S. Highway 287 *in* Geology of Yellowstone Park area: Wyoming Geological Association 33rd Annual Field Conference Guidebook, p. 340-342.

Middlebrooks, T.A., 1940, Fort Peck Slide: American Society of Civil Engineers, Proceedings Papers, v. 66, no. 10, p. 1729-1748.

_____, 1942, Fort Peck slide: American Society of Civil Engineers, Proceedings—Discussion, v. 68, no. 1, p. 152-156.

Montagne, J., 1972, The role of geology in interdisciplinary studies of the Gallatin Canyon area, Gallatin County, Montana *in* Crazy Mountains Basin: Montana Geological Society, Annual Field Conference Guidebook 21, p. 187-190.

Montagne, J., and Chadwick, R.A., 1982, Cenozoic history of the Yellowstone Valley between Yellowstone Park and Livingston Montana *in* Geology of Yellowstone Park area: Wyoming Geological Association 33rd Annual Field Conference Guidebook, p. 31-51.

Mudge, M.R., 1965, Rockfall-avalanche and rockslide-avalanche deposits at Sawtooth Ridge, Montana: Geological Society of America Bulletin, v. 76, p. 1003-1014.

National Earthquake Information Center, 1993, Largest earthquakes in the United States: Largest earthquake in Montana: Hebgen Lake, Montana 1959 08 18 06:37:13 UTC (08/17), 7.3M, MMX *in* Stover, C.W., and Coffman, J.L., Seismicity of the United States, 1568-1989 (revised): U.S. Geological Survey, Professional Paper 1527: U.S. Geological Survey, World Data Center for Seismology, Denver, 2 p.

Nelson, G.E., 1984, Cryopediments in the Bighorn Canyon area, south-central Montana *in* Fourth International Conference on Permafrost, Final Proceedings: National Academy Press, p. 327-332.

Nelson, W.H., Prostka, H.J., Williams, F.E., Elliott, J.E., and Peterson, D.L., 1980, Geology and Mineral resources of the North Absaroka Wilderness and Vicinity, Park County, Montana: U.S. Geologic Survey Bulletin 1447, 101 p., 2 plates.

O'Neill, M.J., 1997, Field guide: Neotectonic evolution of the upper Madison Valley, southwest Montana *in* Northwest Geology—The edge of the Crazies: Geology where the mountains meet the prairie: Tobacco Root Society 22nd Annual Field Conference with the Montana Geological Society.

Oelfke, J.G., and Butler, D.R., 1985, Lichenometric dating of calcareous landslide deposits, Glacier National Park, Montana: Northwest Geology, v. 14, p. 7-10.

Pariseau, W.G., and Stout, K., 1972, Open pit mine slope stability; the Berkeley Pit *in* Stability of rock slopes: Proceedings of the 13th Symposium on Rock Mechanics, p. 367-395.

_____, 1974, Open pit mine slope stability at the Berkeley Pit *in* Voight, B., et al, eds., Rock Mechanics, the American Northwest: International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 191-196.

Parker, F.S., and Andrews, D.A., 1939, The Mizpah coal field, Custer County, Montana: U.S. Geological Survey, Bulletin 906-C, p. 85-133.

Parret, C., 1988, Fire-related debris-flows in the Beaver Creek drainage, Lewis and Clark County, Montana, *in* Subitsky, S. (ed), Selected papers in the hydrologic sciences: U.S. Geological Survey Water-Supply Paper 2330, p. 57-67.

Porter, K.W., 1991, Preliminary map of the Lewistown area, central Montana (Lewistown 30 x 60-minute quadrangle, Montana): Montana Bureau of Mines and Geology, Open-File Report MBMG 239, 14 p., scale 1:100,000.

Prostka, H.J., 1967, Effect of landslides on the course of Whitetail Creek, Jefferson County, Montana: U.S. Geological Survey Professional Paper, 575-B, p. 80-82.

Qamar, A.I., Stickney, M.C., 1983, Montana earthquakes, 1869-1979: Montana Bureau of Mines and Geology, Memoir 51, 79 p., 3 sheets.

Reeves, F., 1927, the landslide origin of the thrust faults around Bearpaw Mountains [abstract]: Washington Academy of Science Journal, v. 17, issue 5, p. 127.

_____, 1946, Origin and mechanics of the thrust faults adjacent to the Bearpaw Mountains, Montana: Geological Society of America, Bulletin 57, issue 11, p.1033-1047.

Richards, P.W., 1955, Geology of the Bighorn Canyon—Hardin area, Montana, Wyoming: U.S. Geological Survey Bulletin 1026, 93 p., 7 plates.

_____, 1957, A contribution to general geology: Geology of the area east and southeast of Livingston, Park County Montana: U.S. Geological Survey Bulletin 1021-L, p. 385-438, 3 plates.

Ritter, D.F., 1967, Terrace development along the front of the Beartooth Mountains, southern, Montana: Geological Society of America Bulletin, v. 78, p. 467-484.

_____, 1978, Accelerated bank erosion during the ten year flood of a high-energy river, southern Montana: Geological Society of America, Abstracts with Programs, v.10, no. 6, p. 283.

Richards, P.W., 1955, Geology of the Bighorn Canyon-Hardin area, Montana and Wyoming: U.S. Geological Survey Bulletin 1026, 93 p., 7 plates.

Roberts, A.E. Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: U.S. Geological Survey Professional Paper 526-C, 120 p., 3 plates.

Ruppel, E.T., 1962, A Pleistocene ice sheet in the northern Boulder Mountains, Jefferson, Powell, and Lewis and Clark Counties, Montana: U.S. Geological Survey Bulletin 1141-G, 22 p.

Samuelson, W.J., and Curtiss, R.E., 1960, Geology of Madison Valley slide, Appendix 5 *in* U.S. Corps of Engineers, Madison River Montana, Montana report on flood emergency, Madison River slide: U.S. Corps of Engineers, V. 2, Appendixes, p. V-1-V-3.

Schmidt, J.C., 1980, Landslides in the Missouri River trench, Charles M. Russell National Wildlife Refuge, north-central Montana: Geological Society of America, Rocky Mountain Section, 33rd Annual meeting, abstracts with programs, v. 12, no. 6, p.303.

Schmidt, R.G., Pecora, W.T., and Hearn, B.C., Jr., 1964, Contributions to general geology—Geology of the Cleveland quadrangle Bearpaw Mountains Blaine County, Montana: U.S. Geological Survey Bulletin 1141-P, 26 p., 1 plate.

Scholten, R., 1974, Deformational mechanism in the northern Rocky Mountains of the United States *in* International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington, p. 181-185.

Shaw, C.W., 1985, Mass movements of the Gravelly Range, southwestern Montana *in* Beaver, P.C., ed., Geology and mineral resources of the Tobacco Root Mountains and adjacent region, "A homecoming to the Tobacco Roots": Guidebook of the Annual Tobacco Root Geological Society Field Conference, v. 10, p. 16.

Shroder, J.F., Jr., Giardino, J.R., and Butler, D.R., 1976, Dendrochronologic analysis of rock glaciers and snow avalanches *in* Abstracts of the Fourth biennial meeting of the American Quaternary Association: American Quaternary Association, National Conference, v. 4, p.115.

Smith, D.L., 1983, Guidebook of the fold and thrust belt, west-central Montana: Montana Bureau of Mines and Geology, Special Publication 86, 98 p., 3 sheets.

Smith, J.F., Jr., Witkind, I.J., Trimble, D.E., 1959, Contributions to general geology—Geology of the Lower Marias River Area Choteau, Hill, and Liberty Counties, Montana: U.S. Geological Survey Bulletin 1071-E, p. 121-155, 3 plates.

Smith, R.M., and Schuster, R.L., 1971, Engineering properties of glacial lake deposits in the Missouri River Canyon, Montana *in* Proceedings of the ninth engineering geology and soils engineering symposium: Idaho Department of Highways, Boise, p. 65-89.

Soward, K.S., 1965, Geology of damsites on Flathead River mouth to Flathead Lake, Lake and Sanders Counties, Montana: U.S. Geological Survey Water-supply Paper 1550, 91 p., 4 plates.

Stuart, D.G., 1974, Impacts of large recreational developments upon semi-primitive environments: The Gallatin Canyon case study: Center for interdisciplinary studies and Montana Agricultural Experiment Station, Montana State University, 127 p.

Thom, W.T., Jr., Hall, G.M., Wegemann, C.H., and Moulton, G.F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana: U..S. Geological Survey Bulletin 856, 200 p., 15 plates.

Tucker, T.E., Aram, R.B., Brinker, W.F., and Grabb, R.F., Jr., 1981, Guidebook—Southwest Montana: Montana Geological Society Field Conference and Symposium, 408 p., 8 sheets.

U.S. Army, Corps of Engineers, 1960, Madison River, Montana, report on flood emergency, Madison River slide; V. 1, Main Report: U.S. Army Engineer District, Omaha, Nebraska, 28 p.

U.S. Army, Corps of Engineers, 1960, Madison River, Montana, report on flood emergency, Madison River slide; V. 2, Appendixes: U.S. Army Engineer District, Omaha, Nebraska, 28 p.

U.S. Geological Survey, 1964, The Hebgen Lake, Montana Earthquake of August 17, 1959: U.S. Geological Survey Professional Paper 435, 242 p., 5 plates.

Voight, B., 1979, Wedge rockslides, Libby Dam and Lake Koocanusa, Montana *in* Voight, B., ed., Rock slides and rock avalanches; Volume 2, engineering sites: Elsevier Scientific Publishing Company, Amsterdam, Netherlands, p. 281-315.

Wanek, A., A., and Barclay, C.S.V., 1966, Contributions to economic geology—Geology of the Northwest quarter of the Anaconda quadrangle Deer Lodge County, Montana: U.S. Geological Survey Bulletin 1222-B, 28 p., 2 plates.

Ward, P.N., and Hall, R.D., 1982, Rock glaciers of the Tobacco Root Range, southwestern Montana: Geological Society of America, Rocky Mountain Section, 35th annual meeting, abstract with programs, v. 14, no. 6, p. 353.

Warren, W.C., 1959, Contributions to economic geology--Reconnaissance geology of the Birney-Broadus coal field, Rosebud and Powder River Counties, Montana: U.S. Geological Survey Bulletin 1072-J, p 561-585, 8 plates.

Weber, W.M., and de la Montagne, J.M, 1966, Snow avalanches in Gallatin County, Montana, during May 1964 [abstract]: Geological Society of America, Special Paper 87, p. 306.

Wilde, E.M., and Bartholomew, M.J., 1986, State-wide inventory and hazard assessment of deep-seated landslides in Montana: 37th Annual Highway Symposium, Abstracts and Programs, p. 5.

Williams, D.A., and Armstrong, J.E., 1970, Investigation of a large landslide associated with Construction of I-15 near Dillon, Montana *in* Proceedings of the 8th annual Engineering geology and soils engineering symposium: Idaho Department of Highways, Boise, p. 91-108.

Witkind, I.J., 1960, Hebgen Lake, Montana, earthquake of August 17, 1959 [abstract]: American Association of Petroleum Geologists, Bulletin, V. 44, No. 6, p. 962.

_____, 1971, Geologic map of the Barker quadrangle, Judith Basin and Cascade Counties, Montana: U.S. Geological Survey Geologic Quadrangle Map GQ-898, scale 1:62,500.

Witkind, I.J., 1974, Some details of the Hebgen Lake, Montana, earthquake of August 17, 1959 *in* Voight, B., and Voight, M.A., eds., Rock Mechanics—The American Northwest: University Park Experimental Station, College of Earth and Mineral Sciences, Pennsylvania State University, p. 126-133.

Witkind, I.J., and Hadley, J.B., 1959, Geological Survey undertakes concentrated investigation of Montana earthquake: Geotimes, vol. 4, no. 3, p.12-17.

Witkind, I.J., Myers, W.B., Hadley, J.B., Hamilton, W., and Fraser, G.D., 1962, Geologic features of the earthquake at Hebgen Lake, Montana, August 17, 1959: Seismological Society of America Bulletin, v. 52, p. 163-180.

Wolfe, P.E., 1964, Late Cenozoic uplift and exhumed Rocky Mountains of central western Montana: Geological Society of America Bulletin, v. 75, p. 493-502.

Zimmerman, E.A., 1966, Geology and ground-water resources of western and southern parts of Judith Basin, Montana: Montana Bureau of Mines and Geology, Bulletin 50-A, 33 p., 4 plates.

F.3.0 THESIS BIBLIOGRAPHY

Aadland, R.K., 1979, Cambrian stratigraphy of the Libby Trough, Montana: University of Idaho, Ph.D. Dissertation, 236 p.

Alexander, R.G., Jr., 1955, Geology of the Whitehall area, Montana: Yellowstone-Bighorn Research Association, Thesis, 111 p.

Beuerman, K., 1982, A study of the copper segregation process applied to copper concentrate from the Weed Concentrator at Butte, Montana: Montana College of Mineral Science and Technology, Masters Thesis, 178 p.

Bieler, B.H., 1955, Primary uranium mineralization in some hydrothermal vein deposits in the Boulder Batholith, Montana: Pennsylvania State University, Ph.D. Dissertation, 147 p.

Bierwagen, E.E., 1964, Geology of the Black Mountain area, Lewis and Clark and Powell Counties, Montana: Princeton University, thesis, 120 p.

Black, J.L.Y., 1984, Soil mineralogy used to distinguish solifluction deposits formed under a periglacial environment on the Boulder Batholith, Jefferson County, Montana: Montana State University, Bozeman, Masters Thesis, 111 p.

Bole, G.R., 1962, The geology of a part of the Manhattan quadrangle, Gallatin County, Montana: University of California, Berkeley, Masters Thesis, 84 p.

Bolle, A.W., 1959, The basis of multiple use management of public lands in the North Fork of Flathead River, Montana: Harvard University: Ph.D. Dissertation, 267 p.

Bryden, E.L., 1950, Geology of an area north of Gardiner Montana: Wayne State University, Detroit Mi., Master Thesis, 47 p.

Butler, D.R., 1976, An analysis of slopes affected by snow avalanches and related mass-wasting features in a portion of Glacier National Park, Montana: University of Nebraska, Omaha, 156 p.

Christie, H.H., 1961, Geology of the southern part of the Gravelly Range, southwestern Montana: Oregon State University, Corvallis, Masters Thesis, 150 p.

Cordua, W.S., 1973, Precambrian geology of the southern Tobacco Root Mountains, Madison County, Montana: Indiana University, Ph.D. Dissertation, 247 p.

Czimer, M.A., The description and origin of the Big Slide, southern Montana: University of Southern Illinois, Carbondale, Masters Thesis, 62 p., 3 plates.

Dahl, G.G., Jr., 1971, General geology of the area drained by the North Fork of the Smith River, Meagher County, Montana: Montana College of Mineral Science and Technology, Masters Thesis, 58 p.

Douglas, E.B., 1899, The Neocene lake beds of western Montana and descriptions of some new vertebrates from the Loup Fork: University of Montana, Missoula, Masters Thesis, 27 p., 4 plates.

Douglas, M.R., 1954, Geology and geomorphology of the south-central Big Snowy Mountains, Montana: University of Kansas, Masters Thesis, 105 p.

Eble, E., 1976, Precambrian geology of the Hell roaring Mountain area, southwest Beartooth Mountains, Montana and Wyoming: Northern Illinois University, Masters Thesis, 77 p.

Egan, R.T., 1971, Geology of the Badger-Birch Creek area, Glacier and Pondera Counties, Montana: University of Montana, Missoula, Masters Thesis, 92 p.

Enderlin, W.I., 1973, A study of underground mine heat sources: Phase II, evaluating underground heat sources in deep mines: Montana College of Mineral Science and Technology, Masters Thesis, p. 134.

Engstrom, D.B., 1953, Geology of part of Centennial Mountain quadrangle, Bearpaw Mountains, Montana: University of California, Berkeley, Masters Thesis, 62 p.

Feichtinger, S.H., 1970, Geology of a portion of the Norris quadrangle with emphasis on Tertiary sediments, Madison and Gallatin Counties, Montana: Montana State University, Bozeman, Masters Thesis, 89 p.

Feucht, A.T., 1971, Geology of the Swift Reservoir area, Sawtooth Range, Pondera and Teton Counties, Montana: University of Montana, Missoula, Masters Thesis, 59 p.

Fox, K.F., 1960, Geology of the Mill Creek basin, Park County, Montana: Montana College of Mineral Science and Technology, Masters Thesis 85 p.

Freeman, V.L., 1954, Geology of part of the Johnny Gulch Quadrangle, Montana: University of California, Berkeley, 81 p.

Gary, S.D., 1980, Quaternary geology and geophysics of the upper Madison valley, Madison County, Montana: University of Montana, Missoula, Masters Thesis, 76 p.

Geldon, A.L., 1979, Hydrology and water resources of the Missoula basin, Montana: University of Montana, Missoula, Masters Thesis, 114 p.

Goolsby, J.E., 1972, East Rock glacier of Lone Mountain, Madison and Gallatin Counties, Montana: Montana State University, Masters Thesis, 74 p.

Griffith, E.F., 1982, Environmental geology of the southeast margin of the Gallatin Valley, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 106 p.

Gucwa, P.R., 1971, Gravity sliding (Recent) south of Bearpaw Mountains, Montana: University of Texas, Austin, Masters Thesis, 60 p.

Gunn, S.H., 1991, Isotopic constraints on the crustal evolution of southwestern Montana: University of California, Santa Cruz, Ph.D., Dissertation, 190 p.

Hall, F.W., II, 1969, Bedrock geology, north half of Missoula 30' x 60' quadrangle, Montana: University of Montana, Missoula, Ph.D. Dissertation, 294 p.

Hall, W.B., 1961, Geology of part of the upper Gallatin valley of southwestern Montana: University of Wyoming, Laramie, Ph.D. Dissertation, 239 p.

Hallager, W.S., 1980, Geology of Archean gold-bearing metasediments near Jardine, Montana: University of California, Berkeley, Ph.D. Dissertation, 136 p.

Halvorson, J.W., 1982, Depositional history and subsurface correlation of lithofacies of the Castle Reef Dolomite in northern Montana disturbed belt: Montana College of Mineral Science and Technology, Masters Thesis, 52 p.

Hanniman, M.R., 1982, Moisture and associated nonaqueous volatile loss of coal during drying processes: Montana College of Mineral Science and Technology, Masters Thesis, 102 p.

Harrington, C.C., 1970, Differentiation of alpine moraines and mass wasted deposits utilizing fabric and textural properties: Indiana University, Bloomington, Ph.D. Dissertation, 174 p.

Hayes, G.S., 1981, Geologic stability of Mystic Lake dam, Gallatin County, Montana: A computer simulation of potential flood hazards from the failure of the dam: Montana State University, Bozeman, Masters Thesis, 120 p.

Hirst, B., 1976, Precambrian geology of the Cottonwood Creek area, Montana and Wyoming: Northern Illinois University, Masters Thesis, 76 p.

Hoffman, J.D., 1980, Water use, groundwater conditions and slope failure on benchlands in western Montana—The Darby slide example: University of Montana, Missoula, Masters Thesis, 48 p.

Hruska, D.C., 1967, Geology of the Dry Range area Meagher County, Montana: Montana College of Mineral Science and Technology, Masters Thesis, 89 p.

Johnson, A.C., 1964, The geology of the Big Ben area, Cascade County, Montana: University of Michigan, Ph.D. Dissertation, 85 p.

Johnson, P.P., 1981, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana: University of Montana, Missoula, Master Thesis, 88 p.

Kehew, A.E., 1971, Environmental geology of part of the West Fork basin, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 55 p.

Kramer, S.L., 1985, Liquefaction of sands due to non-seismic loading: University of California, Berkeley, Ph.D. Dissertation, 375 p.

Krause, H.H., 1964, Geology of the Saddle Mountain-Carten Creek area, Powell County, Montana: University of Kansas, Masters Thesis, 57 p.

Kupsch, W.O., 1950, Geology of the Tendoy-Beaverhead area, Beaverhead County, Montana: University of Michigan, Ph.D. dissertation, 251 p.

Landis, C.A., 1963, Geology of the Graphite Mountain-Tepee Mountain Area, Montana-Idaho: Pennsylvania State University, University Park, Masters Thesis, 153 p.

Le Van, D.C., and McLean, W.F., 1951, Structure and stratigraphy of the Red Canyon area, Gallatin County, Montana: University of Michigan, Master Thesis, 66 p.

McKelvey, G.E., 1967, Lithofacies of the Wallace and related formations of the Belt series: Franklin and Marshall College, Masters Thesis, 1 v.

McLean, J.R., 1971, Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains: University of Saskatchewan, Ph.D. Dissertation, 96 p.

Melson, W.G., 1964, Geology of the Lincoln area, Montana and contact metamorphism of impure carbonate rocks: Princeton University, Ph.D. Dissertation, 153 p, 5 plates.

Mero, W.E., 1962, The geology of Black Lion Mountain and a portion of Canyon Creek, Beaverhead County, Montana: University of California, Santa Barbara, Master Thesis, 56 p.

M'Gonigle, J.W., Structure of the Maiden Peak area, Beaverhead Range, Montana-Idaho: Pennsylvania State University, University Park, Masters Thesis, 146 p.

Montagne, C., 1976, Slope stability evaluation for land capability reconnaissance in the northern Rock Mountains: Montana State University, Bozeman, Ph.D. Dissertation, 229 p.

Moore, G.T., 1956, The geology of the Mount Fleecer area, Montana: Indiana University, Ph.D. Dissertation, 88 p.

Moran, J.L, 1971, Structure and stratigraphy of the Sheep Mountain area, Centennial Range, Montana-Idaho: Oregon State University, Corvallis, Masters Thesis, 175 p.

Murray, C.L., 1973, Structure and stratigraphy of the Jefferson Mountain area, Centennial Range, Idaho-Montana: Oregon State University, Corvallis, Masters Thesis, 108 p.

Nelson, G.E., 1983, Origin and paleoenvironmental significance of pediments in the Bighorn Canyon area of south-central Montana: University of Kansas, Lawrence, PhD .Dissertation, 175 p.

Obert, K.R., 1962, Geology of the Sheep Mountain-Gray Jockey Peak area, Beaverhead County, Montana: University of California, Masters Thesis, 80 p.

Oelfke, J.G., 1956, The location and analysis of landslides along the Lewis Overthrust Fault, Glacier National Park, Montana: Oklahoma State University, Masters Thesis, 133 p., 5 sheets.

Pickens, K.L., 1980, A study of the Hebgen Lake, Montana, area fault scarps and knick points twenty years after the 1959 earthquake: State University of New York at Binghamton, Masters Thesis.

Reynolds, S.T., 1962, Geology of the northern half of the Bannack Quadrangle, Beaverhead County, Montana: University of California, Berkeley, Masters Thesis, 57 p.

Rose, R.R., 1967, Stratigraphy and structure of the southern Madison Range, Madison and Gallatin Counties, Montana: Oregon State University, Corvallis, Masters Thesis, 172 p.

Sanderson, R.L., Jr., 1969, Parametric effects on slope stability analysis: Montana State University, Bozeman, Masters Thesis, 78 P.

Sayers, F.E., 1962, The geology of a portion of the Manhattan quadrangle, the Horseshoe Hills area, Gallatin County, Montana: University of California, Berkeley, Masters Thesis, 67 p.

Schrunk, V.K., 1976, Surficial geology of a part of the northeast flank of the Bridger Range, Montana: Montana State University, Bozeman, Masters, 132 p.

Searle, F.D., 1981, Evaluation of factors affecting heavy metals in discharge from Warm Springs Pond: Montana College of Mineral Science and Technology, Masters Thesis, 199 p.

Sollid, S.A., 1973, Surficial geology of the Porcupine drainage basin, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 100 p.

Smith, W.K., 1980, Long-term highwall stability in the northwestern Powder River Basin, Wyoming and Montana: University of Arizona, Tucson, Ph.D. Dissertation, 124 p.

Tanner, J.J., 1949, Geology of the Castle Mountain area, Montana: Princeton University, Ph.D. Dissertation, 153 p., 14 plates.

Tansley, W., 1933, Geology and petrography of the Tobacco Root Mountains, Montana: University of Chicago, Ph.D. Dissertation, 54 p.

Todd, S.G., 1969, Bedrock geology of the southern part of Tom Miner basin, Park and Gallatin Counties, Montana: Montana State University, Bozeman, Masters Thesis: Montana State University, Bozeman, Masters Thesis, 63 p.

Tysdal, R.G., 1966, Geology of a part of the north end of the Gallatin Range, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 92 p.

_____, 1970, Geology of the north end of the Ruby Range, southwestern Montana: University of Montana, Ph.D. Dissertation, 187 p.

Umpleby, J.B., Drainage history of Warm Springs Creek, central Montana: University of Utah, Masters Thesis, 37 p.

Van der Poel, W.I., III, 1979, A reconnaissance of Late Tertiary and Quaternary geology, geomorphology, and contemporary surface hydrology of the Rattlesnake Creek watershed, Missoula County, Montana: University of Montana, Missoula, Masters Thesis, 85 p.

Vhay, J.S., 1934, The geology of a part of the Beartooth Mountains front near Nye, Montana: Princeton University, Ph.D. Dissertation, 112 p.

Viele, G.W., 1960, The geology of the Flat Creek area, Lewis and Clark County, Montana: University of Utah, Ph.D. Dissertation, 86 p.

Walsh, T.H., 1971, Quaternary geology of the east portion of the West Fork basin, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 83 p.

_____, 1976, Glaciation of the Taylor Basin area, Madison Range, southwestern Montana: University of Idaho, Moscow, Idaho, Ph.D. dissertation, 244 p.

Waring, J., 1975, Depositional environments of the Lower Cretaceous Muddy sandstone, southeastern Montana: Texas A&M University, Ph.D. Dissertation, 195 p.

Weber, W.M., 1965, General geology and geomorphology of the Middle Creek area, Gallatin County, Montana: Montana State University, Bozeman, Masters Thesis, 86 p.

White, R.E., 1974, Stratigraphy and structure of the Cedar Creek area of the Madison Range, Madison County, Montana: Oregon State University, Corvallis, Masters Thesis, 134 p.

F.4.0 NEWSPAPER ARTICLES BIBLIOGRAPHY

Barr, R., 1959, More than one person blamed prowling bears when trailers began to rock in earthquake: Montana Standard Newspaper, August 20, 1959.

Calcaterra, J., 1959, Severe earthquake rocks Butte-Minor damage widespread in Mining City: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Man who escaped death says prayer salvation: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Ennis people jolted as siren wails: Montana Standard Newspaper, August 20, 1959.

Calcaterra, J., and Quinn, F., 1959, Ennis residents are allowed to resume normal activities: Montana Standard Newspaper, August 20, 1959.

Coleman, J.D., 1959, People in Ennis feel worst yet to come--moving the mountain: Montana Standard Newspaper, August 19, 1959.

Coyle, E.A., 1959, Curious advised to avoid Madison River area; rock slides continuing: Montana Standard Newspaper, August 20, 1959.

Cuts, M., 1959, Civil defense response here is great: Montana Standard Newspaper, August 19, 1959.

Dieckmann, J., 1959, Survivors of quake overjoyed by Butte's friendliness: Montana Standard Newspaper, August 23, 1959.

Lewis, K., 1959, Sad, mad, glad, grateful--These were the people in the quake: Montana Standard Newspaper, August 20, 1959.

_____, Amazing cooperation in tragedy significant: Montana Standard Newspaper, August 23, 1959.

Maddox, T., 1959, Quake claims another victim—Area rocked by 5 new earth tremors: Montana Standard Newspaper, August 21, 1959.

Montana Standard, 1959, Hebgen dam out; Ennis is evacuated—Bulletin: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Butte scared by tremor: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Quake damages old building in Virginia City: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Three Forks shaken; Rock slide results: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Butte's seismograph not to be opened until 7 this morning: Montana Standard Newspaper, August 18, 1959.

_____, 1959, Butte danger apparently past—Another bad earthquake now unlikely: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Butte ready to house 750 Ennis refugees: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Tremblor brings wakefulness to Anaconda area: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Slight damage done in Dillon: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Only one Montana route open to Yellowstone Park: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Tremors 'slight' at Wyoming parks: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Hebgen Lake is 65 miles around: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Quake did not damage park wonders, but traffic tied-up: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Nearly 3,000 quakes recorded in state: Montana Standard Newspaper, August 19, 1959.

_____, 1959, '25 quake just missed train: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Many of stranded persons at dam badly hurt: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Crews cut through to probe disaster region: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Evacuation forced into high speed: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Plans are under way to dynamite barrier: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Flying rancher from Dillon tells of flight over Hebgen Dam area, signals from people: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Deer Lodge man dies after quake strikes: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Billing couple hurt when big wave hits: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Butte receives its first quake casualty: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Three brothers tell of their parents death: Montana Standard Newspaper, August 19, 1959.

_____, 1959, People from Butte assisting victims: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Cool efficiency marks hospital: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Bozeman Red Cross clears information: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Emergency food ready if needed: Montana Standard Newspaper, August 19, 1959.

_____, 1959, St. Vincent de Paul assists refugees: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Lt. Gov. Cannon in Hebgen area: Montana Standard Newspaper, August 19, 1959.

_____, 1959, The earthquake (editorial): Montana Standard Newspaper, August 19, 1959.

_____, 1959, Alderman Skelley and family safe: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Wise River Johns, egged on, describe how quake played shell game trick on the hens: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Room reserved: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Butte civil defense alert is canceled: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Montana prison cellblock damaged so badly it is ordered torn down: Montana Standard Newspaper, August 20, 1959.

_____, 1959, Team to survey quake region: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Hebgen dam is under study, engineer describes damage: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Answer to big question very confusing: Montana Standard Newspaper, August 21, 1959.

_____, 1959, What did 'O.K., S.O.S.' mean?: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Size of landslide is measured: Montana Standard Newspaper, August 21, 1959.

_____, 1959, School of Mines seismograph 'blew its top': Montana Standard Newspaper, August 21, 1959.

_____, 1959, Quake inquiries flood into Red Cross office: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Potter is designated quake coordinator: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Power Co. asks chimney check: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Quake-jarred wall falls on Butte home: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Gas shut off in building here: Montana Standard Newspaper, August 21, 1959.

_____, 1959, State has no funds to replace roads ruined by tremors: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Paul Cannon cautions quake sightseers: Montana Standard Newspaper, August 21, 1959.

_____, 1959, Visitor are barred from quake region—Move aimed at vandals and thieves: Montana Standard Newspaper, August 22, 1959.

_____, 1959, No more quake bodies expected: Montana Standard Newspaper, August 22, 1959.

_____, 1959, School of Mines seismograph called invaluable in study of earthquake: Montana Standard Newspaper, August 22, 1959.

_____, 1959, State newsmen are welcomed to Yellowstone; superintendent says conditions are safe: Montana Standard Newspaper, August 22, 1959.

_____, 1959, Old Faithful Inn closed for now: Montana Standard Newspaper, August 22, 1959.

_____, 1959, Forced decision saved family: Montana Standard Newspaper, August 22, 1959.

_____, 1959, Deer Lodge man sings to ease quake fears: Montana Standard Newspaper, August 22, 1959.

_____, Tourist travel reduced by quake, but Butte figures good for year: Montana Standard Newspaper, August 23, 1959.

_____, Demolition work confusing to Butte tourists: Montana Standard Newspaper, August 23, 1959.

_____, West Yellowstone man tells how he sounded alert after quake: Montana Standard Newspaper, August 23, 1959.

_____, Virginia City Players entertain evacuees form Madison valley: Montana Standard Newspaper, August 23, 1959.

_____, Red Cross there: Montana Standard Newspaper, August 23, 1959.

_____, T & T did good job: Montana Standard Newspaper, August 23, 1959.

_____, Madison slide would overflow Berkeley Pit: Montana Standard Newspaper, August 23, 1959.

_____, Dam employee explains 'O.K.—S.O.S.: Montana Standard Newspaper, August 24, 1959.

_____, Just dropped in: Montana Standard Newspaper, August 24, 1959.

_____, Quake 'fear' list cut to about 39: Montana Standard Newspaper, August 25, 1959.

_____, Madison towns seek travelers: Montana Standard Newspaper, August 25, 1959.

_____, Dog, happy to see someone, found in quake region: Montana Standard Newspaper, August 25, 1959.

_____, Metcalf asks SBA for worker in earthquake area: Montana Standard Newspaper, August 25, 1959.

_____, Engineers study Quake Lake for flood threat: Montana Standard Newspaper, August 25, 1959.

_____, Earthquake Lake to be major attraction—Biggest Landslide in the World: Montana Standard Newspaper, August 25, 1959.

Moore, R., 1959, Once happy, carefree faces of vacationing Americans grim, some stained with blood: Montana Standard Newspaper, August 19, 1959.

Poole, L.T., 1959, That silly helpless feeling comes from being 'all shook up': Montana Standard Newspaper, August 18, 1959.

Quinn, F., 1959, Terrifying experiences are related by youthful tourists: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Big Mountain was just chopped away: Montana Standard Newspaper, August 19, 1959.

_____, 1959, Virginia City opens arms to refugees: Montana Standard Newspaper, August 19, 1959.

_____, Neighborliness was never more evident: Montana Standard Newspaper, August 23, 1959.

Quinn, F., and Calcaterra, J., 1959, At least 18 are dead in tremors—Rescue workers seek victims of slide in Madison Canyon; Hebgen Dam expected to hold: Montana Standard Newspaper, August 19, 1959.

Raff, C., 1959, West Yellowstone is strange mixture of quietness, action: Montana Standard Newspaper, August 22, 1959.

United Press, Inc., 1959, Earthquake is widely felt in Northwest: Montana Standard Newspaper, August 18,1959.

Deseret News Newspaper, 1959: Latest quake items reported at a glance: Deseret News Newspaper, 18 August, 1959.

_____, 1959: Here's a partial list of tremblor victims: Deseret News Newspaper, 18 August, 1959.

_____, 1959: Residents sketch scene of nature on rampage—Quake area report: Deseret News Newspaper, 18 August, 1959.

_____, 1959: Quake disrupts rail service to Yellowstone: Deseret News Newspaper, 18 August, 1959.

_____, 1959: Tremors hit S.L. home, family flees in night: Deseret News Newspaper, 18 August, 1959.

_____, 1959, Slide at Hebgen traps Ogden pair, children: Deseret News Newspaper, 19 August, 1959.

_____, 1959, U seismograph tilts crazily during shocks: Deseret News Newspaper, 19 August, 1959.

_____, 1959, Visitors at Park say quakes 'Big Adventure': Deseret News Newspaper, 19 August, 1959.

_____, 1959, Night of horror told by California woman: Deseret News Newspaper, 19 August, 1959.

_____, 1959, Survivors tell of terrifying quake wrath—Heartbreak, joy: Deseret News Newspaper, 19 August, 1959.

_____, 1959, Nature shatters man's work at Hebgen Lake: Deseret News Newspaper, 20 August, 1959.

_____, 1959, Solons plan tour of quake area—On-spot study: Deseret News Newspaper, 21 August, 1959.

_____, 1959, Activity inside Park 'near normal' again: Deseret News Newspaper, 21 August, 1959.

_____, 1959, Slide no protection to downstream areas: Deseret News Newspaper, 21 August, 1959.

_____, 1959, 40 Utah residents unreported in quake: Deseret News Newspaper, 21 August, 1959.

_____, 1959, Utahan tells terror of quake near dam: Deseret News Newspaper, 22 August, 1959.

_____, 1959, Utah families rejoice as 'lost' return—had not idea: Deseret News Newspaper, 22 August, 1959.

_____, 1959, Utah's missing drops to 11 in earthquake: Deseret News Newspaper, 22 August, 1959.

_____, 1959, Disaster aid urged for quake region—Montana Governor calls conference: Deseret News Newspaper, 24 August, 1959.

_____, 1959, No Utahans seen missing in slide: Deseret News Newspaper, 24 August, 1959.

_____, 1959, Rites at slide end search for Utahans: Deseret News Newspaper, 24 August, 1959.

Madsen, R., 1959, Lake search turns up no new quake victims—Diver probe water; Crews comb slide: Deseret News Newspaper, 20 August, 1959.

_____, 1959, Round-clock watch put on split dam—In case of new quakes: Deseret News Newspaper, 21 August, 1959.

_____, 1959, More quakes shake up Montana disaster area—S.L. Patrol joins hunt for victims: Deseret News Newspaper, 22 August, 1959.

Madsen, R., and Teuscher, M.D., 1959, Grim search continues for victims of quake—New jolts Threaten dam, slide: Deseret News Newspaper, 21 August, 1959.

Ost, G., 1959, Sisters relate terror in tremor-filled night: Deseret News Newspaper, 19 August, 1959.

Teuscher, M.D., 1959, Hillside cracked wide; damage everywhere—Reporter at scene: Deseret News Newspaper, 18 August, 1959.

_____1959, W. Yellowstone almost like a ghost town: Deseret News Newspaper, 20 August, 1959.

Teuscher, M.D., and Fehr, W., 1959: 16 reported dead as quakes smash West Yellowstone area—Dam cracked; Mountains fall: Deseret News Newspaper, 18 August, 1959.

Teuscher, M.D., and Beck, D., 1959, More tremor victims hunted in massive slide—Two Utahans reported among known dead: Deseret News Newspaper, 19 August, 1959.

Associated Press, 1959, Much of Montana feels tremor—Many cities report feeling shock: Montana Standard Newspaper, August 18, 1959.

Hungry Horse News, 1984, Highway 2 covered by rock slide: Hungry Horse News, Thursday, May 10, 1984, p. 5.

Hungry Horse News, 1981, Mudslide blocks Going-to-the-Sun Road: Hungry Horse News, Thursday, January 1, 1981, p. 1.

Hungry Horse News, 1981, Mudslide blocks Going-to-the-Sun Road: Hungry Horse News, Thursday, January 1, 1981, p. 6.

Waldrop, H.A., and Hyden, Associated Press, 1959, Much of Montana feels tremor—Many cities report feeling shock: Montana Standard Newspaper, August 18, 1959.

F.5.0 GENERAL LANDSLIDE BIBLIOGRAPHY

Adams, J.,1981, Earthquake dammed lakes in New Zealand: Geological Society of America Geology, v. 9, p. 215-219.

Anderson, J.G., 1906, Solifluction, a component of subaerial denudation: Journal of Geology, v. 14, p. 91-112.

Andrus, R.D., and Youd, T.L., 1987, Subsurface investigation of a liquefaction induced lateral spread, Thousand Springs Valley, Idaho: U.S. Army Engineer Waterways Experimental Station, Vicksburg, Mississippi, Paper GL-87-8.

Ashley, G.M., Shaw, J., and Smith, N.D., 1985, Glacial sedimentary environments: Society of Economic Paleontologists and Mineralogists, SEPM Short Course no. 16, 246 p.

Banks, D.C., and Strohm, W.E, 1974, Calculations of rock-slide velocities: Proceedings of the Third International Society for Rock Mechanics, Congress, V. 2, Part B, p. 839-847.

Baskerville, C.A., Lee, F.T., and Ratte, C.A., 1993, Landslide hazards in Vermont: U.S. Geological Survey Bulletin 2043, 23 p.

Baum, R.L., 1994, Contributions of artesian water to progressive failure of the upper part of the Delhi Pike landslide complex, Cincinnati, Ohio: U.S. Geological Survey Bulletin 2059-D, 14 p.

Baum, R.L., and Fleming, R.W., 1989, Landslides and debris flows in Ephraim Canyon, central Utah: U.S. Geological Survey Bulletin 1842-C, 12 p., 1 plate.

______, 1991, Use of longitudinal strain in identifying driving and resisting elements of landslides [with Suppl. Data 01-19]: Geological Society of America Bulletin, v. 103, issue 8, p. 1121-1132.

Baum, R.L., and Johnson, A.M., 1993, Steady movement of landslides in fine-grained soils--a model for sliding over and irregular slip surface: U.S. Geological survey Bulletin 1842-D, 28 p.

______, 1996, Overview of landslide problems, research and mitigation, Cincinnati, Ohio area: U.S. Geological Survey Bulletin 2059-A, 33 p.

Baum, R.L., Chleborad, A.F., and Schuster, R.L., 1998, Landslides triggered by the winter 1996-97 storms in the Puget lowland, Washington: U.S. Geological Survey Open-File Report 98-239, 18 p.

Baum, R.L., Fleming, R.W., and Johnson, A.M., 1993, Kinematics of the Aspen Grove landslide, Ephraim Canyon, central Utah: U.S. Geological survey Bulletin 1842-F, 34 p., 1 plate.

Bell, D.H., ed., 1992, Proceedings, Sixth international symposium on landslides: A.A. Balkema, Rotterdam, Netherlands, vol. 1 and 2, 1495p.

Bhatia, S.K., and Quast, D., 1984, The behavior of collapsible soil under cyclic loading: National Conference on Geomechanics-interaction, Institution of Engineers, Australia, v. 84, no. 2, p. 73-77.

Bloom, A.L., 1978, Geomorphology, A systematic analysis of late Cenozoic land forms, Chapter 8: Mass-Wasting and hillslope evolution: Prentice-Hall, Inc., p. 163-196.

Bond, J.G., 1975, General geology of northern Idaho and western Montana and its implication on highway construction [abstract]: Proceedings of the Highway Geology Symposium, v. 26, p. 1-2.

Bonnard, C., ed., 1988, Proceedings, Fifth international symposium on landslides: A.A. Balkema, Rotterdam, Netherlands, vols. 1,2,3, 1564p.

Brabb E.E., 1989, Landslides: Extent and economic significance in the United States, *in* Brabb, E.E., and Harrod, B.L., editors, Landslides: Extent and Economic Significance: Proceedings of the 28th International Geological Congress, Symposium on Landslides, Washington D.C., July, 1989: A.A. Balkema, Rotterdam, p. 25-50.

Bradley, C.C., 1970, The location and timing of deep slab avalanches: Journal of Glaciology, v. 9, no. 56, p. 253-261.

Brunsden, B, and Prior, D.B., eds., 1984, Slope Instability: John Wiley & Sons, 620 p.

Canadian Geotechnical Society, 1984, Proceedings, Fourth international symposium on Landslides: Toronto, Canada, Vols. 1,2,3, 1484p.

Cannon, S.H., Powers, P.S., Pihl, R.A., and Rogers, W.P., 1995, Preliminary evaluation of the fire-related debris flows on Storm King Mountain, Glenwood Springs, Colorado: U.S. Geological Survey Open-File Report 95-508, 38 p., 1 plate, scale 1:10,000.

Case, J.C., Earthquakes and related geologic hazards in Wyoming: The Geological Survey of Wyoming, 22 p., 1 plate.

Chleborad, A.F., 1997, Temperature, snowmelt, and the onset of spring season landslides in the central Rocky Mountains: U.S. Geological Survey Open-File Report 97-27, 35 p.

_____, 1998, Use of air temperature data to anticipate the onset of snowmelt-season landslides: U.S. Geological Survey Open-File Report 98-124, 16 p.

Ciarla, M., 1986, Wire Netting for rockfall protection *in* Proceedings of the 37th annual highway Geology symposium—Geotechnical aspects of construction in mountainous terrain: Montana Department of Highways and Montana Division-Federal Highway Administration, p. 100-118.

Coe, J.A., Godt, J.W., Ellis, W.L., Savage, W.Z., Savage, J.E., Powers, P.S., Varnes, D.J., and Tachker, P., 2000, Seasonal movement of the Slumgullion landslide as determined from GPS observations, July 1998-July 1999: U.S. Geological Survey Open-File Report 00-101, 47 p.

Colorado Geological Survey, 1988, Colorado landslide hazard mitigation plan: Colorado Geological Survey, Department of Natural Resources, Denver, Colorado, Bulletin 48, 149 p.

Colton, R.B., 1979, Geologic hazards in the Rocky Mountain region: Geological Society of America, Abstract with Programs, v. 11, no. 6, p.268-269.

Committee on Ground Failure Hazards, Commission on Engineering and Technical Systems, and National Research Council, 1985, Reducing losses from landsliding in the United States: National Academy Press, Washington, D.C., 41 p.

Cook, H.E., and Enos, P., 1977, Deep-water carbonate environments: Society of Economic Paleontologists and Mineralogists, Special Publication No. 25, 336 p.

Cook, H.E., Hine, A.C., and Mullins, H.T., 1983, Platform margin and deep water carbonates: Society of Economic Paleontologists and Mineralogists, Short Course No. 12.

Costa, J.E., and Schuster, R.L., 1988, The formation and failure of natural dams: Geological Society of America Bulletin V. 100, Issue 7, p. 1054-1068.

Costa, J.E., 1988, The formation and failure of natural dams: Geological Society of America Bulletin, v. 100, p. 1054-1068.

Costa, J.E., and Wieczorek, G.F., eds., 1987, Debris flows/avalanches: Process, recognition and mitigation: The Geological Society of America Reviews in Engineering Volume VII, 239 p.

Crandell, D.R., 1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geological Survey Professional Paper 677, 75 p.

Crandell, D.R., and Gard, L.M., Jr., 1959, Geology of the Buckley quadrangle, Washington: U.S. Geological Survey Geologic Quadrangle Map CQ-125, scale 1:24,000.

Crovelli, R.A., 2000, Probability models for estimation of number and costs of landslides: U.S. Geological Survey Geological Open-File Report 00-249, 23 p.

Crozier, M.J., 1986, Landslides: causes, consequences and environment: London, Croom Helm, 252 p.

Cruden, D.M., and Lucchitta, B.K., 1980, A large landslide on Mars; discussion and reply: Geological Society of America Bulletin, v. 91, issue 1, p. I.

Davis, R.A., ed., 1978, Coastal sedimentary environments: Springer-Verlag, 420 p.

_____, 1984, Structural geology of rocks and regions: John Wiley & Sons, 492 p.

Dott, R.H., Jr., 1973, Dynamics of subaqueous gravity depositional processes *in* Weimer, R.J., ed., Sandstone reservoirs and stratigraphic concepts II: American Association of Petroleum Geologists Reprint Series No. 8, p. 25-49.

Doyle, L.J., and Pilkey, O.H., 1979, Geology of continental slopes: Society of Economic Paleontologists and Mineralogists, Special Publication No. 27, 374 p.

Dragovich, J.D., and McKay, D.T., 2000, Holocene glacier peak lahar deposits in the lower Skagit River valley, Washington *in* Washington Geology, vol. 28, No. ½, September 2000: Washington State department of Natural Resources, p. 19-21.

Ellen, S.D., and Wieczorek, G.F., eds., 1988, Landslides, floods, and marine effects of the storm of January 3-5, 1982, in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 1434, p. 310, 14 plates.

Erskine, C.F., 1973, Landslides in the vicinity of the Fort Randall reservoir, South Dakota: U.S. Geological Survey Professional Paper 675, 65 p., 5 plates.

Eversman, S.R., 1970, A vegetational comparison between avalanche paths and nonavalanche paths [abstract] *in* 1st meeting of American Quaternary Association: American Quaternary Association: p. 41.

Feltis, R.D., 1973, Geology and water resources of eastern part of Judith River Basin, Montana: Montana Bureau of Mines and Geology Bulletin 87, 51 p., 3 plates.

Fitzhugh, T.L., Smith, W.K, and Savage, W.Z., 1976, Stability of highwalls in surface coal mines, western Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report 76-846, 52 p.

Fleming, R.W., Spencer, G.S., and Banks, D.C., 1970, Empirical study of behavior of clay shale slopes; Volume I: National Institute of Coal Research, Bulletin 15, 397 p.

Fleming, R.W., and Johnson, A.M., 1994, Landslides in colluvium: U.S. Geological Survey Bulletin 2059-B, 24 p., 1 plate.

Flores, R.M., and Kaplan, S.S., eds., 1985, Cenozoic Paleogeography of the west-central United States—Rocky Mountain Paleogeography Symposium 3: The Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, 460 p.

Friedman, G.M. and Sanders, J.E., 1978, Principles of sedimentology: John Wiley and Sons, Inc., 792 p.

Garcia, M.O., and Hull, D.M., 1994, Turbidites from giant Hawaiian landslides; results from Ocean Drilling Program Site 842: Geological Society of America, Geology, v. 22, issue, p. 159-162.

Gill, J.R., Denson, N.M., 1957, Regional Synthesis; eastern Montana and the Dakotas: Trace elements, Investigations Report: U.S. Geological Survey, Report Number TEI-0700, p. 160-171.

Gill, J.R., Denson, N.M., 1957, Regional Synthesis; eastern Montana and the Dakotas: Trace elements, Investigations Report: U.S. Geological Survey, Report Number TEI-0690, p. 419-425.

Gomberg, J.S., Bodin, P, Savage, W.Z., and Jackson, M.E., 1995, Landslide faults and tectonic faults, analogs?; the Slumgullion earth flow, Colorado: Geological Society of America, Geology, v. 23, Issue 1, p. 574.

Griggs, A.B., 1976, The Columbia River Basalt Group in the Spokane quadrangle, Washington, Idaho, Montana: U.S. Geological Survey, Bulletin 1413, 39 p., 1 sheet, scale 1: 250,000.

Haneberg, W.C., and Gokce, A. O., 1994, Rapid water-level fluctuations in a thin colluvium landslide west of Cincinnati, Ohio: U.S. Geological Survey Bulletin 2059-C, 16 p.

Hansen, W.R., 1965, Effects of the March 27, 1964, at Anchorage, Alaska: U.S. Geological Survey Professional Paper 542-A, 68p.

Harp, E.L., Wilson, R.C., and Wieczorek, G.F., 1981, The Guatemala earthquake of February 4, 1976: Landslides from the February 4, 1976 Guatemala earthquake: U.S. Geological Survey Professional Paper 1204-A, 35 p., 2 plates.

Harty, K.M., 1991, Landslide map of Utah: Utah Geological and Mineral Survey Map 133, 28 p, 2 sheets, scale 1:500,000.

Higashi, A., and Corte, A.E., 1971, Solifluction: A model experiment: Science, v. 171, p. 480-482.

Hoffman, J.D., 1982, Water use, groundwat6er conditions, aslope failure on benchlands in western Montana; the Darby Slide example: Geological Society of America, Rocky Mountain Section, 35th annual meeting, abstracts with programs, v. 14, no. 6, p. 315.

Hovius, N., Stark, C.P., and Allen, P.A., 1997, Sediment flux from a mountain belt derived by landslide mapping: Geological Society of America, Geology, v. 25, issue 3, p. 231-234.

Hovius, N., Stark, C.P., Tutton, M.A., and Abbott, L.D., 1998, Landslide-driven drainage network evolution in a pre-steady state mountain belt; Finisterre Mountains, Papua, New Guinea: Geological Society of America, Geology, v. 26, issue 12, p. 1071-1074.

Hsu, K.J., 1975, Castastrophic debris streams (sturzstroms) generated by rock falls: Geological Society of America Bulletin, v. 86, no.1, p. 129-140.

Hustrulid, W.A., McCarter, M.K., and Van Zyl, K.J.A., eds., 2000, Slope stability in surface mining: Society for Mining, Metallurgy, and Exploration, Inc., 442 p.

Hutchinson, J.N., 1968, Mass movement, *in* Fairbridge, R.W., ed., Encyclopedia of geomorphology: Reinhold, New York, p. 688-695.

IAEG Commission on Landslides, 1990, Suggested nomenclature for landslides: Bulletin of the International Association of Engineering Geology, no. 41, p. 13-16.

International Congress on Rock Mechanics, 1974, Advances in Rock Mechanics: Proceedings of the Third Congress of the International Society of Rock Mechanics, Denver Colorado, September 1-7: National Academy of Sciences, Washington.

Iverson, R.M., and Major, J.J., 1987, Rainfall, ground-water flow, and seasonal movement at Minor Creek Landslide, northwestern California; physical interpretation of empirical relations [with Suppl. Data 87-24]: Geological Society of America Bulletin, v. 99, issue 4, p. 579-594.

Jibson, R.W., and Keefer, D.K., 1988, Landslides triggered by earthquakes in the central Mississippi Valley, Tennessee and Kentucky *in* Russ, D.P. and Crone, A.J., eds., The New Madrid, Missouri, earthquake region--Geological, seismological, and geotechnical studies: U.S. Geological Survey Professional Paper 1336-C, 24 p., 1 plate.

_____, 1993, Analysis of the seismic origin of landslides; examples from the New Madrid seismic zone: Geological Society of America Bulletin, v. 105, issue 4, pages 521-536.

_____, 1994, Analysis of the origin of landslides in the New Madrid seismic zone: U.S. Geological Survey Professional Paper 1538-D, 23 p.

Jochim, C.L., Rogers, W.P., Truby, J.O., Wold, R.L., Jr., Weber, G., and Brown, S.P., 1988, Colorado landslide hazard mitigation plan: Colorado Geological Survey, Department of Natural Resources, Bulletin 48, 149 p.

Jones, F.O., 1973, Landslides of Rio de Janeiro and the Serra das Araras escarpment, Brazil: U.S. Geological Survey Professional Paper 697, 42 p., 2 plates.

Jones, F.O., Embody, D.R., and Peterson, W.L., 1961, Landslides along the Columbia River Valley, northeastern Washington: U.S. Geological Survey Professional Paper 367, 98 p., 6 plates.

Keefer, D.K., ed., 1998, The Loma Prieta, California, earthquake of October 17, 1989: Strong ground motion and ground failure: U.S. Geological Survey Professional Paper 1551-C, 185 p., 8 plates.

Keefer, D.K., and Johnson, A.M., 1983, Earth flows: morphology, mobilization and movement: U.S. Geological Survey Professional Paper 1264, 56 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, Issue 4, p. 406-421.

Keller, E.A., 1976, Chapter 5: Landslides and related phenomena: Charles E. Merrill Publishing Company, A Bell & Howell Company, P. 97-124.

_____, 1976, Environmental geology: Charles E. Merrill Publishing Company, 488 p.

Kelsey, H.M., 1978, Earth flows in Franciscan melange, Van Druzen River basin, California: Geological Society of America, Geology, v. 6, issue 6, p. 361-364.

Kiersch, G.A., 1964, Vaiont reservoir disaster: Civil Engineering, v. 34, p. 32-39. Kirby, M.J., 1967, Measurement and theory of soil creep: Journal of Geology, v. 75, p. 36-374.

Kliche, C.A., 1999, Rock slope stability: Society for Mining, Metallurgy, and Exploration, Inc., 253 p.

Kockelman, W.J., 1986, Some techniques for reducing landslide hazards: Bulletin of the Association of Engineering Geologists, v. XXIII, no. 1, p.29-52.

Krieger, M.H., 1977, Large landslide, composed of megabreccia, interbedded in Miocene basin deposits, southeastern, Arizona: U.S. Geological Survey Professional Paper 1008, 25 p., 4 plates.

Lee, F.T., Smith, W.K., and Savage, W.Z., 1976, Stability of highwalls in surface coal mines, western Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report 76-846, 52 p.

Leet, L.D., Judson, S., and Kauffman, M.E., 1978, Physical Geology, 5th edition: Prentice-Hall, Inc., 490 p.

Legget, R.F., 1973, Cities and geology: McGraw-Hill, New York.

Legros, F., Cantagrel, J., and Devouard, B., 2000, Pseudotachylyte (frictionite) at the base of the Arequipa volcanic landslide deposit (Peru): Implications for emplacement Mechanisms: The Journal of Geology, v. 108, p. 601-611.

Levin, H.L., 1981, Contemporary physical geology: Saunders College Publishing, 579 p.

Lipman, P.W., and Mullineaux, D.R., 1981, The 1980 eruptions of Mount St. Helens, Washington,: U.S. Geological Survey Professional Paper 1250, 844 p., 1 plate.

Lucchitta, B.K., 1978, A large landslide on Mars: Geological Society of America Bulletin, v. 89, Issue 11, p. 1601-1609.

Mackin, J.H., 1937, Erosional history of the Big Horn Basin, Wyoming: Geological Society of America Bulletin, vol. 48, June 1, 1937, p. 813-894, 11 plates.

Marangunic, C., and Bull, C., 1968, The landslide on the Sherman Glacier, *in* The great Alaskan earthquake of 1964, v. 3, "Hydrology": National Academy of Science Publication 1603, Washington, D.C., p. 383-394.

Maund, J.G., Eddleston, M., eds., 1998, Geohazards in engineering geology: Geological Society, London, Engineering Geology Special Publications, no. 15, 448 p.

McCalpin, J., 1985, Lichenometric dating of large rockslide and rockfall-avalanche deposits in Western U.S., limitations of the method: Geological Society of America, 38th annual meeting, Abstracts with programs, v.17, no. 4., p. 255.

McEwen, A.S., 1989, Mobility of large rock avalanches; evidence from Valles Marineris, Mars: Geological Society of America, Geology, v. 17, issue 12, p. 1111-1114.

McSaveney, M.J., and Griffiths, G.A., 1987, Drought, rain, and movement of a recurrent earth flow complex in New Zealand: Geological Society of America, Geology, v. 15, issue 7, p. 643-646.

Miall, A.D., 1984, Principles of sedimentary basin analysis: Springer-Verlag, 490 p.

Middleton, F.V., and Southard, J.B., 1984, Mechanics of sediment movement: Society of Economic Paleontologist and Mineralogists, Short Course Number 3, 401 p.

Miller, C.H., 1979, Seismic, magnetic and geotechnical properties of a landslide and clinker deposits, Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report 79-952, 56 p.

_____, 1978, Engineering geophysical investigations in the Powder River Basin, Wyoming and Montana *in* Maberry, J.O., ed., The energy lands programs of the U.S. Geological Survey, fiscal year 1976: U.S. Geological Survey, Circular no. C-778, p. 29-30.

Miller, C.H., Ramirez A.L., and Bullard, T.F., 1980, Contributions to General Geology: Seismic properties investigation of the Springer Ranch landslide, Powder River Basin, Wyoming: U.S. Geological Survey Professional Paper 1170-C, 7 p.

Montagne, C., 1980, A multidisciplinary approach to slope stability in the Northern Rock Mountains: Geological Society of America, Rocky Mountain Section, 33rd annual meeting, abstracts with programs, v. 12, no. 6, p. 298.

Moore, H.L., 1986, The construction of a shot-in-place rock buttress for landslide stabilization *in* Proceedings of the 37th annual highway geology symposium—Geotechnical aspects of Construction in mountainous terrain: Montana Department of Highways and Montana Division-Federal Highway Administration, p. 137-157.

Moore, J.G., Bryan, W.B., Beeson, M.H., and Normark, W.R., 1995, Giant blocks in the South Kona Landslide, Hawaii: Geological Society of America, Geology, v. 23, issue 2, p. 574.

Murray, T.L., Lockhart, A.B., Wolfe, E.W., Sharp, T.R, and Fielding, S.E., 2000, Abstracts on geology of Mount Rainier—an automated lahar-detection system for the Carbon and Puyallup Rivers, Wa. *in* Washington Geology, vol. 28, No. ½, September 2000: Washington State Department of Natural Resources, p. 27.

Nicoletti, P.G., and Sorriso-Valvo, M., 1991, Geomorphic controls of the shape and mobility of rock-avalanches: Geological Society of America Bulletin, vol. 103, no.10, p 1365-1373.

Nilsen, T.H., 1972, Preliminary photointerpretation map of landslide and other surficial deposits of the Mount Hamilton quadrangle and part of the Mount Boardman and San Jose quadrangles, Alameda and Santa Clara Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-339, scale 1:62,500.

Nilsen, T.H., Taylor, F.A., and Brabb. E.E., 1976, Recent landslides in Alameda County, California (1940-71): An estimate of economic losses and correlations with slope, rainfall, and ancient landslide deposits: U.S. Geological Survey Bulletin 1398, 21 p., 1 plate.

Nilsen, T.H., and Turner, B.L., 1975, Influence of rainfall and ancient landslide deposits on recent landslides (1950-71) in urban areas of Contra Costa County, California: U.S. Geological Survey Bulletin 1388, 18 p., 2 plates.

Osterwald, H.W., Chleborad, A.F., Dunrud, C.R., Farrow, R.A., Nichols, T.C., Jr., McGregor, E.E., Miller, C.H., Odum, J., Olsen H.W., Savage, W.Z., and Smith W.K., 1977, Part C., Engineering Geologic characteristics: U.S. Geological Survey Open-File Report Of 77-292, p. 71-96.

Pearce, A.J., and O'Loughlin, C.L., 1985, Landsliding during a M 7.7 earthquake; influence of geology and topography: Geological Society of America, Geology, v. 13, issue 12, p. 855-856.

Pearce, A.J., and Watson, A.J., 1986, Effects of earthquake-induced landslides on sediment budget and transport over a 50-yr period: Geological Society of America, Geology, v. 14, issue 1, p. 52-55.

Plummer, C.C., and McGeary, D., 1985, Physical Geology, third edition: Wm. C. Brown Publishers, 513 p.

Pomeroy, J.S., 1982, Landslides in the Greater Pittsburgh region, Pennsylvania: Recognition of Landslide areas on aerial photographs and a study of factors affecting slope stability in an urban to rural setting: U.S. Geological Survey Professional Paper 1229, 48 p., 12 plates.

Poulos, S.J., Castro, G., and France, J.W., 1985, Liquefaction evaluation procedure: Journal of Geotechnical Engineering, v. 111, no. 6, p. 772-792.

Prellwitz, R., W., 1974, Simplified slope design for low standard roads in mountainous areas *in* Erickson, L.F., ed., Twelfth annual engineering geology and soils engineering symposium: Idaho Transportation Division of Highways, Idaho State University.

Pringle, P.T., 2000, Abstracts on geology of Mount Rainier--Buried forest of Mount Rainier volcano—evidence for extensive Holocene inundation by lahars in the White, Puyallup, Nisqually and Cowlitz River valleys *in* Washington Geology, vol. 28, No. ½, September 2000: Washington State department of Natural Resources, p. 28.

Prior, D.B., and Stephens, N., 1972, Some movement patterns of temperate mudflows: Examples from Ireland: Geological Society of American Bulletin, v. 83, p. 2533-2543.

Prostka, H.J., 1978, Heart Mountain fault and Absaroka volcanism, Wyoming and Montana, U.S.A. *in* Voight, B., ed., Rockslides and avalanches; Vol. 1, Natural phenomena: Elsevier Scientific Publication Company, Amsterdam, Netherlands, Vol. 14A, p. 423-437.

Radbruch-Hall, D.H., Varnes, D.J., and Savage, W.Z., 1976, Gravitational spreading of steep-sided Ridges (sackung) in western United States: International Association of Engineering geology, no. 14, p. 23-35.

______, 1976, Gravitational spreading of steep-sided Ridges ("sackung") in Jacobson, G., Western United States *in* Section 13, The contribution of geology towards management of the environment: International Association of English Geology, Bulletin 14, p. 23-25.

Reading, H.G., ed., 1978, Sedimentary environments and facies: Elsevier, New York, 557 p.

Reineck, H.E., and Singh, I.B., 1980, Depositional sedimentary environments, with reference to terrigenous clastics, second revised and update edition: Springer-Verlag, 549 p.

Reynolds, M.W., and Dolly, E.D., eds., 1983, Mesozoic Paleogeography of the west-central United States—Rocky Mountain Paleogeography Symposium 2: The Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, 391 p.

Rickert, D.A., Ulman, W.J., and Hampton, E.R., eds., 1979, Synthetic fuels development—Earth-science considerations: U.S. Department of the Interior/Geological Survey, 45 p.

Ritter, D.F., 1978, Process Geomorphology: Wm. C. Brown company publishers, 603 p.

Roering, J.J., Kirchner, J.W., Sklar, L.S., and Dietrich, W.E., 2001, Hillslope evolution by nonlinear Creep and landsliding: An experimental study *in* Geological Society of American, Geology: Geological Society of America, February 2001, vol.29, no.2, p. 143-146.

Russ, D.P. and Crone, A.J., ed., 1988, The New Madrid, Missouri, earthquake region--Geological, seismological, and geotechnical studies: U.S. Geological Survey Professional Paper 1336-C, 24 p., 1 plate.

Sangrey, D.A., 1985, A national program for landslide hazards reduction: Geological Society of America, Geology, v. 13, issue 5, p. 323.

Savage, W.Z., and Smith, W.K., 1978, Stability of highwalls in surface coal mines, western Powder River basin *in* Maberry, J.O., compiler, The energy lands programs of the U.S. Geological Survey, fiscal year 1976: U.S. Geological Survey, Circular C-778, p.35-36.

_____, 1986, A model for the plastic flow of landslides: An application of the theory of Coulomb plasticity to the flow of landslides: U.S. Geological Survey Professional Paper 1385, 32 p.

Scholle, P.A. and Spearing, D., eds., 1982, Sandstone depositional environments: The American Association of Petroleum Geologists Memoir 81, 410 p.

Scholle, P.A., Bebout, D.G., and Moore, C.H., eds., 1983, Carbonate depositional environments: American Association of Petroleum Geologists, Memoir 33, 708 p.

Schultz, A.P., and Jibson, R.W., ed., 1989, Landslide processes of the eastern United States and Puerto Rico: The Geological Society of America, Special Paper 236, 102 p.

Schuster, R. L., 1986, Landslide Dams: Processes, risk, and mitigation: American Society of Civil Engineers, Geotechnical Special Publication No. 3., 164 p.

_____, 1994, Hazard mitigation for landslide dams *in* Proceedings, Seventh International Congress, International Association of Engineering Geology, 5-9 September, 1994, Portugal: A.A. Balkema, Rotterdam, Brookfield.

Schwab, W.C., Lee, H.J., Twichell, D.C., eds., 1993, Submarine landslides: Selected studies in the U.S. exclusive economic zone: U.S. Geological Survey Bulletin 2002, 204 p., 1 plate.

Sharpe, C.F.S., 1938, Landslides and related phenomena: Pageant Books, Inc., Paterson, N.J., 137 p., [Reprint, 1960].

Shreve, R.L., 1966, Sherman landslide, Alaska: Science, v. 154, p. 1639-1643.

_____, 1968, The Blackhawk landslide: Geological Society of America Special Paper 108, 47 p.

Slosson, J.E., Keene, A.G., and Johnson, J.A., eds., 1992, Landslides/landslide mitigation: The Geological Society of America, Reviews in engineering volume IX, 120 p.

Smedes, H.W., 1966, Geology and igneous petrology of the northern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S., Geological Survey Professional Paper 510, 116 p., 3 plates.

Smith, R.L., 1960, Ash flows: Geological Society of America Bulletin, v. 71, p.795-842.

Smith, W.K., 1980, Long-term highwall stability in the northwestern Powder River Basin, Wyoming and Montana: U.S. Geological Survey Open-File Report, OF 80-1229, 131 p.

Stanley, D.J., and Moore, G.T., eds., 1983, The Shelfbreak: Critical interface on continental margins: Society of Economic Paleontologists and Mineralogists, Special Publication No. 33, 467 p.

Steinberg, T., 1995, Slide Mountain—or the folly of owning nature: University of California Press, 212 p.

Stoopes, G.R., and Sheridan, M.F., 1992, Giant debris avalanches from the Colima volcanic complex, Mexico; implications for long-runout landslides ((100) km) and hazard assessment: Geological Society of America, Geology, v. 20, issue 4, p. 299-302.

Stover, C.W., and Coffman, J.L., 1993, Seismicity of the United States, 1568-1989 (revised): U.S. Geological Survey, Professional Paper 1527.

Strahler, A.N. and Strahler, A.H., 1978, Modern physical geography: John Wiley and Sons, New York, 502 p.

Strecker, M.R., and Marrett, R., 1999, Kinematic evolution of fault ramps and its role in development of landslides and lakes in the northwestern Argentine Andes: Geological Society of America, Geology, v. 27, issue 4, p. 307-310.

Swanson, F.J., and Dyrness, C.T., 1975, Impact of clear-cutting and road construction on soil erosion by landslides in the western Cascade Range, Oregon: Geological Society of America, Geology, v. 3, issue 7, p. 393-396.

Sykora, D.W., and Davis, G.M., 1984, Installation of soil anchors in a talus slope: Proceedings of the Annual Engineering Geology and Soils Engineering Symposium, v. 21, p. 149-166.

Terzaghi, K., 1950, Mechanisms of landslides, *in* Paige, S., ed., Applications of geology to engineering practice: The Geological Society of America, New York, p. 83-123.

Toy, T.J., 1977, Hillslope form and climate: Geological Society of America Bulletin, v. 88, p. 16-22.

Transportation Research Board, 1978, Landslides—Analysis and control: National Academy of Science, National Research Council, Special Report 176.

Tucker, M.E., 1981, Sedimentary petrology—An introduction: John Wiley & Sons, Geoscience Texts Volume 3, 252 p.

Turner, A.K., and Schuster, R.L.S., eds., 1996, Landslides--Investigation and mitigation: Transportation Research Board, National Research Council, Special Report 247, National Academy Press, 673 p.

Updike, R.E., Egan, J.A., Moriwaki, Y., Idriss, I.M., and Moses, T.L., 1988, A model for earthquake-induced translatory landslides in Quaternary sediments: Geological Society of America Bulletin, v. 100, issue 5, p. 783-792.

Updike, R.G., Olsen, H.W., Schmoll, H.R., Kharaka, Y.K., and Stokoe, K.H.,II, 1988, Geologic and geotechnical conditions adjacent to the Turnagain Heights landslide, Anchorage, Alaska: U.S. Geological Survey Bulletin 1817, 40 p., 5 plates.

U.S. Forest Service, 1982, Goals and tasks of the landslide part of a ground-failure hazards reduction program: U.S. Geological Survey Circular 880, 49p.

U.S. Geological Survey, 1972, Geological, geophysical and engineering investigations of the Loveland Basin landslide, Clear Creek County, Colorado, 1963-65: U.S. Geological Survey Professional Paper 673-A, B, C, D, E, F, G, 43 p.

U.S. Geological Survey, 1988, The Manti, Utah, landslide: Contains a history of the reactivation of the Manti landslide including rates of landslide enlargement and displacement, morphologic changes, physical properties of the landslide debris, and hydrologic changes: U.S. Geological Survey Professional Paper 1311, 69 p., 1 plate.

U.S. Geological Survey, 1997, Debris-flow hazards in the United States: U.S. Geological Survey Fact Sheet 197-97, 4 p.

U.S. Geological Survey, 1997, El Nino and the national landslide hazard outlook for 1997-1998: U.S. Geological Survey Fact Sheet 180-97, 4 p.

U.S. Geological Survey, 1997, Lahars of Mount Pinatubo, Philippines: U.S. Geological Survey Fact Sheet 114-97, 5 p.

U.S. Geological Survey, 1997, What are volcano hazards: U.S. Geological Survey Fact Sheet 002-97, 5 p.

U.S. Geological Survey, 1998, Popular beach disappears underwater in huge coastal landslide—Sleeping Bear Dunes, Michigan: U.S. Geological Survey Fact Sheet 20-98, 5 p.

U.S. Geological Survey, 2000, Landslide hazards: U.S. Geological Survey Fact Sheet 071-00, 2 p.

Van Horn, R., 1975, Largest known landslide of its type in the United States--A failure by lateral spreading in Davis County Utah: Utah Geology, vol. 2, p 82-87.

Varnes, D.J., 1949, Landslide problems of southwestern Colorado: U.S. Geological Survey Circular 31, 13 p.

Varnes, D.J., 1958, Landslide types and processes, *in* Eckel, E.B., ed., Landslides and engineering practice: HRB, National Research Council, Washington, D.C., Special Report 29, p 20-47.

Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: Transportation Research Board, National Academy of Sciences, Washington D.C., p. 11-33.

Varnes, D.J., Radbruch-Hall, D.H., and Savage, W.Z., 1989, Topographic and structural conditions in areas of gravitational spreading of ridges in the western United States: U.S. Geological Survey Professional Paper 1496, 28 p.

Varnes, D.J., Coe, J.A., Godt, J.W., Savage, W.Z., and Savage, J.E., 2000, Measurement of ridge-spreading movements (Sackungen) at Bald Eagle Mountain, Lake, County, Colorado, II: continuation of the 1975-1989 measurements using a global positioning system in 1997 and 1999: U.S. Geological Survey Open-File Report 00-205, 23 p.

Varnes, D.J., Radbruch-Hall, D.H., Varnes, K.L., Smith, W.K., and Savage, W.Z., 1990, Measurements of ridge-spreading movements (Sackungen) at Bald Eagle Mountain, Lake County, Colorado, 1975 -1989: U.S. Geological Survey Open-File Report 90-543, 13p.

Vick, S.G., 1981, Morphology and the role of landsliding in formation of some rock glaciers in the Mosquito Range, Colorado: Geological Society of America Bulletin, v. 92, issue 2, p. I.

Vitek, J.D., Wright, R.H., Campbell, R.H., and Nilsen, T.H., 1975, Preparation and use of isopleth maps of landslide deposits [discussion and reply]: Geological Society of America, Geology, v. 3, issue 4, p. 217-218.

Voight, B., and Pariseau, W.G., 1978, Rockslides and avalanches; an introduction *in* Voight, B, ed., Rockslides and avalanches, Volume 1, Natural phenomena: Elsevier Scientific Publishing Company, Amsterdam, Netherlands, Developments in geotechnical engineering collection, vol. 14A, p.1-67.

Voight, B., and Voight, M.A., 1974, Rock mechanics: the American northwest: University Park: Experimental Station, College of Earth and Mineral Sciences, Pennsylvania State University, 292 p.

Watters, R.J., Bowman, A.D., Zimbelman, D.R., and Crowley, J.K., 2000, Abstracts on geology of Mount Rainier—Significance of rock strength results and slope stability calculations to edifice and flank instability at Mount Rainier *in* Washington Geology, vol. 28, No. ½, September 2000: Washington State department of Natural Resources, p. 29.

Wendell, W.G., Glass, G.B., Breckenridge, R.M., Root, F.K., Lageson, D. and the remote sensing lab, University of Wyoming, 1976, Johnson County, Wyoming--Geologic map atlas and summary of land, water and mineral resources: Geological Survey of Wyoming County Resource Series No. 4, 10 sheets, 1:500,000.

Williams, G.P., and Guy, H.P., 1971, Debris avalanches—a geomorphic hazard, *in* Coates, D.R., ed., Environmental geomorphology: State University of New York Publications in Geomorphology, Binghamton, New York, p. 25-46.

Wilson, J.L., 1975, Carbonate facies in geologic history: Springer-Verlag, 471 p.

Wilson, S.D., 1978, Field instrumentation *in* Schuster, R.L., ed., Landslides; analysis and control: National Research Council, Transportation Research Board, Special Report 176, p.112-138.

Yanev, P., 1970, Peace of mind in earthquake country; how to same your home and life: Chronicle Books, San Francisco, CA., 304 p.

Zaruba, Q., and Mencl, V., 1969, Landslides and their control, 1st ed.: Elsevier, Amsterdam, Netherlands, 205 p.

Zaruba, Q., and Mencl, V., 1982, Landslides and their control, 2nd ed.: Elsevier, Amsterdam, Netherlands, 324 p.

Zimbelman, D.R., Watters, R.J., Crowley, J.K., and Rye, R.O., 2000, Abstracts on geology of Mount Rainier—Non-uniform distribution of volcanic hazards, Mount Rainier *in* Washington Geology, vol. 28, No. 1-2, September 2000: Washington State department of Natural Resources, p. 29.