Rockfall Management System for Tennessee

Final Project Report

Includes:

Final Report - PHASE I

Final Report - PHASE II

Appendices A-L

Submitted to Tennessee Department of Transportation
Division of Materials and Tests

by

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16. Abstract

This final report is the culmination of a major, multi-year effort, beginning in Oct. 2002, to develop and deploy the Tennessee Rockfall Management System (RMS) for U.S. Routes, State Routes and Interstate Highways throughout Middle and East Tennessee. The Tennessee RMS includes a Rockfall Hazard Rating System (RHRS) customized for Tennessee, a rockfall database, field tools and procedures for semi-automated digital data entry in the field, and integration with a GIS to facilitate management decisions. Capabilities of the RMS include built-in error checking, rapid easy updates and seamless downloads to desktop computers. In addition, the project included development of a complete Rockfall Inventory for 78 counties in Middle and East Tennessee, and the collection of all pertinent engineering and geologic data. The project was carried out by personnel from the University of Tennessee, Virginia Tech, and TDOT's Nashville office. Altogether, the equivalent of 124 person-weeks was spent doing the fieldwork, as well as 9 person-weeks spent surveying candidate sites using TRIMS.

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Rockfall Management System for Tennessee

EXECUTIVE SUMMARY

This final report is the culmination of a major, multi-year effort, beginning in Oct. 2002, to develop and deploy the Tennessee Rockfall Management System (RMS) for U.S. Routes, State Routes and Interstate Highways throughout Middle and East Tennessee. The Tennessee RMS includes a Rockfall Hazard Rating System (RHRS) customized for Tennessee, a rockfall database, field tools and procedures for semi-automated digital data entry in the field, and integration with a GIS to facilitate management decisions. Capabilities of the RMS include built-in error checking, rapid easy updates and seamless downloads to desktop computers. In addition, the project included development of a complete Rockfall Inventory for 78 counties in Middle and East Tennessee, and the collection of all pertinent engineering and geologic data. The project was carried out by personnel from the University of Tennessee, Virginia Tech, and TDOT's Nashville office. Altogether, the equivalent of 124 person-weeks was spent doing the fieldwork, as well as 9 person-weeks spent surveying candidate sites using TRIMS.

Acknowledgments

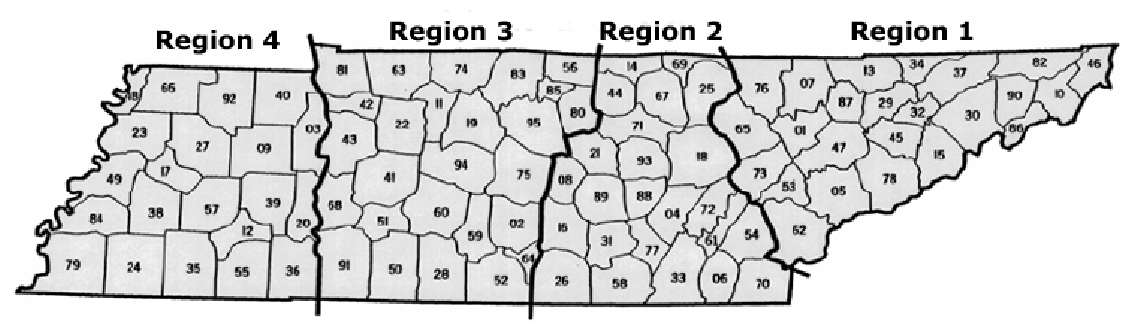
This project would not have been possible without the support of Bill Trolinger, Harry Moore, Len Oliver and Vanessa Bateman from the Tennessee DOT, who helped get the project off the ground and provided support throughout. In particular we appreciate their efforts in making TDOT project files available, providing access to the TRIMS system, participating in focused discussions on the rating system, and training programs, and contributing from their vast reservoirs of knowledge about Tennessee engineering geology and the history of rock slide and road maintenance in Tennessee.

Figure 1. Rock slope on State Route 70 in Hawkins County

We are also extremely grateful to the many students from the University of Tennessee and Virginia Tech who contributed to the field work, and to other aspects of the project. These students include Sam Cain, Chris Vandewater, Derrick Bellamy, Frank Dworak, James Everett, Philip Gray, Lori McDowell, Adam Milam, Diana Miller, Matt Osbourne, Chad Philips, Aaron Short and Chris Beall. The Phase II field work was coordinated by Brad McCarter.

Fieldwork

As part of the project, a complete Rockfall Inventory was developed for 78 counties in Middle and East Tennessee (Figure 2), and all pertinent engineering and geologic data were collected. Due to the magnitude of the task, the fieldwork was divided into two phases. PHASE I was a two-year study of rock slopes in five counties. The initial five counties were selected to represent the different physiographic and geologic regions in Tennessee. PHASE II was a multi-year study to finalize the RMS, implement the RMS along U.S. routes, State Routes and Interstate highways in the remaining counties of East and Middle Tennessee, and training TDOT personnel in the use and maintenance of the RMS.



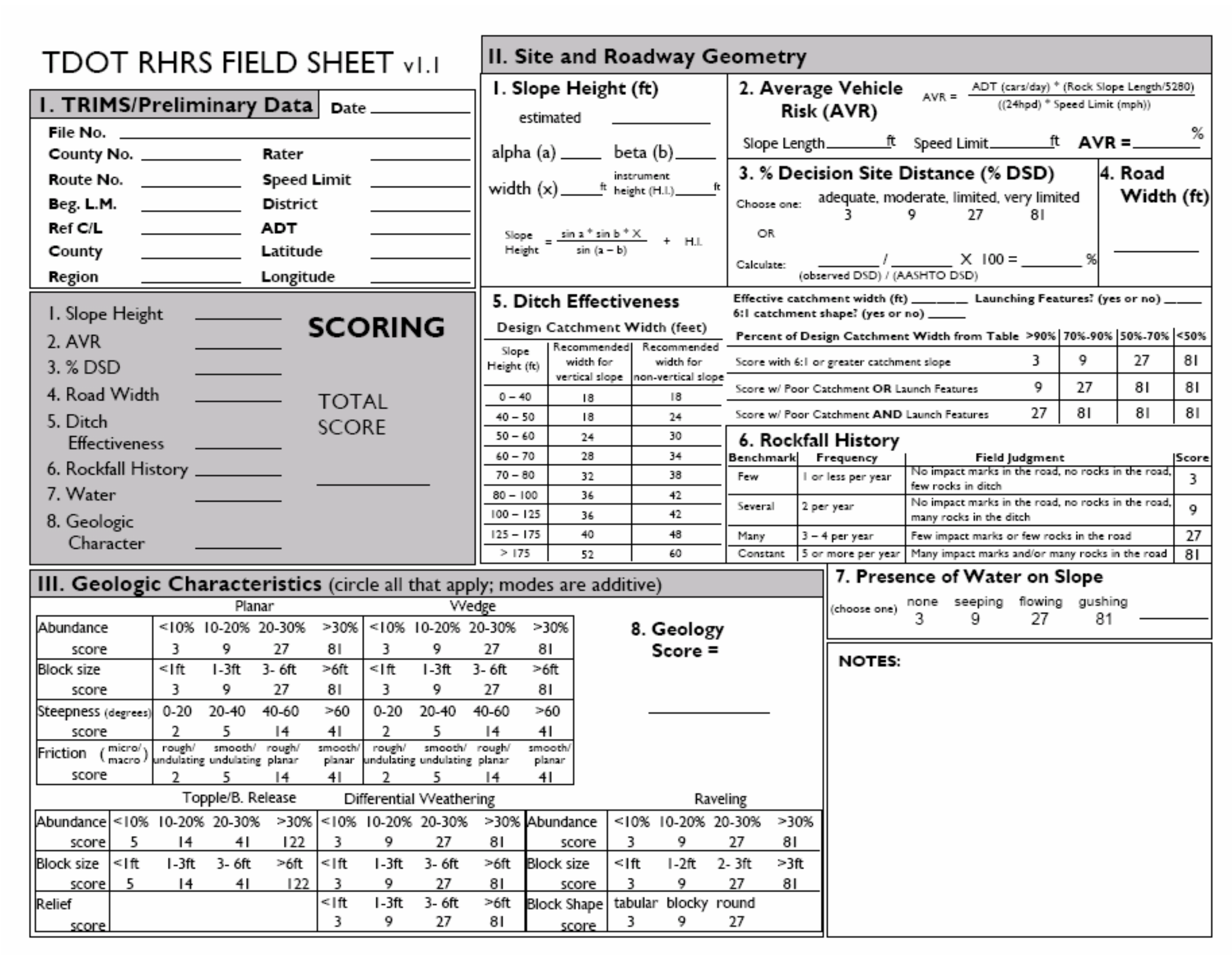
01 Anderson	20 Decatur	39 Henderson	58 Marion	77 Sequatchie
02 Bedford	21 Dekalb	40 Henry	59 Marshall	78 Sevier
03 Benton	22 Dickson	41 Hickman	60 Maury	79 Shelby
04 Bledsoe	23 Dyer	42 Houston	61 Meigs	80 Smith
05 Blount	24 Fayette	43 Humphreys	62 Monroe	81 Stewart
06 Bradley	25 Fentress	44 Jackson	63 Montgomery	82 Sullivan
07 Campbell	26 Franklin	45 Jefferson	64 Moore	83 Sumner
08 Cannon	27 Gibson	46 Johnson	65 Morgan	84 Tipton
09 Carroll	28 Giles	47 Knox	66 Obion	85 Trousdale
10 Carter	29 Grainger	48 Lake	67 Overton	86 Unicoi
11 Cheatham	30 Greene	49 Lauderdale	68 Perry	87 Union
12 Chester	31 Grundy	50 Lawrence	69 Pickett	88 Van Buren
13 Claiborne	32 Hamblen	51 Lewis	70 Polk	89 Warren
14 Clay	33 Hamilton	52 Lincoln	71 Putnam	90 Washington
15 Cocke	34 Hancock	53 Loudon	72 Rhea	91 Wayne
16 Coffee	35 Hardeman	54 McMinn	73 Roane	92 Weakley
17 Crockett	36 Hardin	55 McNairy	74 Robertson	93 White
18 Cumberland	37 Hawkins	56 Macon	75 Rutherford	94 Williamson
19 Davidson	38 Haywood	57 Madison	76 Scott	95 Wilson

Figure 2. Tennessee counties and administrative regions

The hazard rating involved two main procedural steps, preliminary and detailed, as follows.

- Preliminary rating and inventory of rockcuts, which were classified as A (moderate-to-high potential for rocks to reach roadway and/or high historical rockfall activity), B (low-to-moderate potential for rocks to reach roadway and/or moderate historical rockfall activity) or C (negligible-to-low potential for rocks to reach roadway and/or low historical rockfall activity. Extensive use was made of TennDOT's TRIMS system (Tennessee Roadway Information Management System) for this phase. Locations, and photographs of A and B cuts were entered into a geographic database.

- Detailed ratings were then conducted for all the A (high-hazard) slopes. Data were collected using a customized Pendragon form on a PDA (Personal Digital Assistant), with a parallel paper form as backup. These ratings were similar to the RHRS used by the National Highway Institute (NHI, 1993) and included factors related to traffic level, roadway/rockcut geometry, and geological characteristics. Additional photographs were taken at this stage, as well as GPS coordinates and measurements of several parameters, all of which were entered into the geographic database.



TDOT RHRS FIELD SHEET v1.1

I. TRIMS/Preliminary Data Date ______

File No. ______

County No.	______	Rater	______
Route No.	______	Speed Limit	______
Beg. L.M.	______	District	______
Ref C/L	______	ADT	______
County	______	Latitude	______
Region	______	Longitude	______

SCORING

1. Slope Height ______
2. AVR ______
3. % DSD ______
4. Road Width ______
5. Ditch Effectiveness ______
6. Rockfall History ______
7. Water ______
8. Geologic Character ______

TOTAL SCORE ______

II. Site and Roadway Geometry

1. Slope Height (ft)

estimated ______

alpha (a) ____ beta (b) ____

width (x) ____ ft instrument height (H.I.) ____ ft

Slope Height = sin a * sin b * X / sin (a − b) + H.I.

2. Average Vehicle Risk (AVR)

AVR = ADT (cars/day) * (Rock Slope Length/5280) / ((24hpd) * Speed Limit (mph))

Slope Length ____ ft Speed Limit ____ ft **AVR =** ____ %

3. % Decision Site Distance (% DSD)

Choose one: adequate, moderate, limited, very limited — 3, 9, 27, 81

OR

Calculate: ______ / ______ X 100 = ______ % (observed DSD) / (AASHTO DSD)

4. Road Width (ft) ______

5. Ditch Effectiveness

Design Catchment Width (feet)

Slope Height (ft)	Recommended width for vertical slope	Recommended width for non-vertical slope
0 – 40	18	18
40 – 50	18	24
50 – 60	24	30
60 – 70	28	34
70 – 80	32	38
80 – 100	36	42
100 – 125	36	42
125 – 175	40	48
> 175	52	60

Effective catchment width (ft) ______ Launching Features? (yes or no) ______
6:1 catchment shape? (yes or no) ______

Percent of Design Catchment Width from Table	>90%	70%-90%	50%-70%	<50%
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment OR Launch Features	9	27	81	81
Score w/ Poor Catchment AND Launch Features	27	81	81	81

6. Rockfall History

Benchmark	Frequency	Field Judgment	Score
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in ditch	3
Several	2 per year	No impact marks in the road, no rocks in the road, many rocks in the ditch	9
Many	3 – 4 per year	Few impact marks or few rocks in the road	27
Constant	5 or more per year	Many impact marks and/or many rocks in the road	81

III. Geologic Characteristics (circle all that apply; modes are additive)

	Planar				Wedge			
Abundance	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%
score	3	9	27	81	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft
score	3	9	27	81	3	9	27	81
Steepness (degrees)	0-20	20-40	40-60	>60	0-20	20-40	40-60	>60
score	2	5	14	41	2	5	14	41
Friction (micro/macro)	rough/undulating	smooth/undulating	rough/planar	smooth/planar	rough/undulating	smooth/undulating	rough/planar	smooth/planar
score	2	5	14	41	2	5	14	41

8. Geology Score = ______

	Topple/B. Release				Differential Weathering			
Abundance	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%
score	5	14	41	122	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft
score	5	14	41	122	3	9	27	81
Relief					<1ft	1-3ft	3- 6ft	>6ft
score					3	9	27	81

	Raveling			
Abundance	<10%	10-20%	20-30%	>30%
score	3	9	27	81
Block size	<1ft	1-2ft	2- 3ft	>3ft
score	3	9	27	81
Block Shape	tabular	blocky	round	
score	3	9	27	

7. Presence of Water on Slope

(choose one) none 3, seeping 9, flowing 27, gushing 81 ______

NOTES:

Figure 3. Version 1.1 of the RHRS field rating sheet (equivalent to the PDA data entry form)

Results

We give a few of the significant results in this section. Further results, analysis and discussion can be found in the Phase I and II Final Reports.

Distribution of A and B cuts

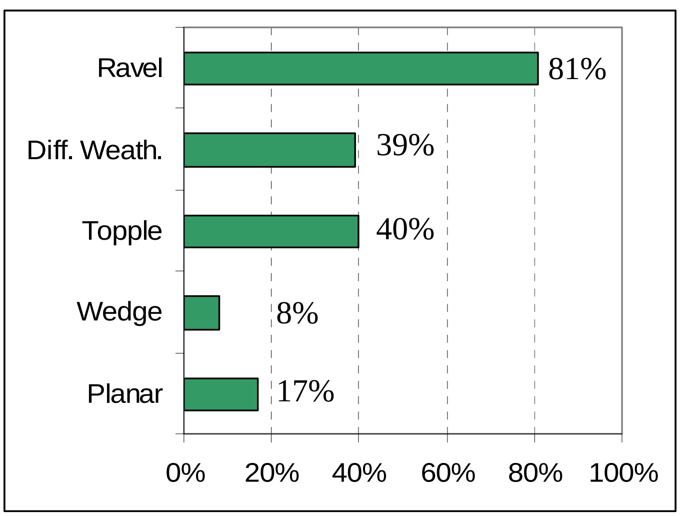
Table 1 shows overall statistics on the number of A-cuts and the number of B-cuts for each TDOT administrative region. It is readily apparent from Table 1 that, for example, Region 1 has over 60% of the A-rated slopes and more than twice as many as any other administrative region. Similar statistics hold for B-rated slopes. It can also be seen that after Region I, Region II has the greatest number of A-rated slopes, but Region III has the greatest number of B-rated slopes.

Table 1. A and B Rockcut ratings (number of cuts) grouped by TDOT Region

Region	A-cuts	B-cuts	Total
I	581	637	1218
II	278	154	432
III	90	194	284
IV	2	1	3
TOTAL	951	986	1937

Distribution by Failure Mode

The five classic modes (Fig. 2) of planar slide, wedge slide, topple, differential weathering and raveling were all encountered. The relative distribution of these failure modes is shown in Fig. 3 (note that more than one mode can apply to a given slope). The most common failure mode was raveling, followed by topple and differential weathering, plane sliding and wedge sliding (Fig. 3)



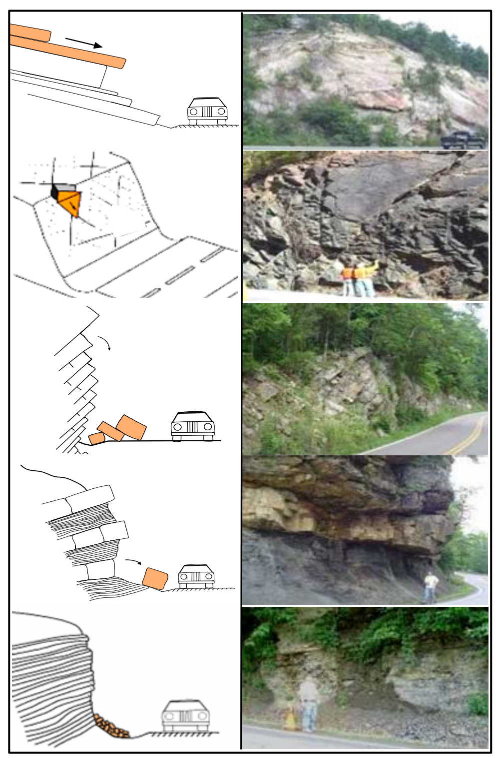


Figure 4. (a) Distribution of failure modes over all A-rated cuts. More than one mode could apply to a given slope; (b). Rock slope failure modes

Distribution by Geologic Character Score

The Geologic Character score contributes roughly one-third of the overall score. Five potential rockfall modes contribute to the Geologic Character sub-score: planar, wedge, topple, differential weathering (DW), and raveling. Of these five failure modes, raveling is the most prevalent with almost a universal occurrence. The other modes are less abundant because the geologic conditions necessary for their presence have limited occurrence in the state. From Fig. 5 it can be seen that the great majority of A-cuts had a Geologic Character Score less than 100, and only a few had a score in excess of 300.

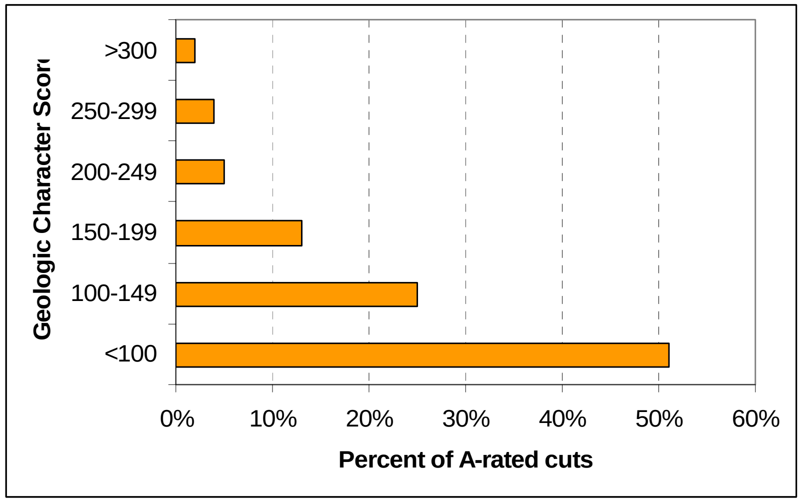


Figure 5. Distribution of Geologic Character score for all A-rated cuts

Distribution by Site and Roadway Geometry Score

Site and Roadway Geometry contributes roughly two-thirds of the overall score. The Site and Roadway Geometry sub-score is totaled from the ratings of five characteristics: ditch effectiveness, decision sight distance (DSD), average vehicle risk (AVR), road width, and slope height.

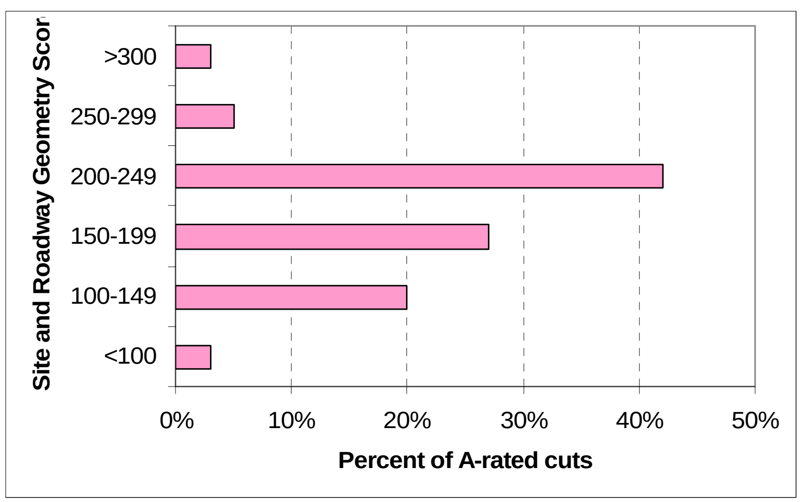


Figure 6. Distribution of Site and Roadway Geometry score for all A-rated cuts

For a maximum score in all Site and Roadway Geometry categories, a rockcut would need to have a height of at least 100 ft, a ditch less than nine ft wide, a roadway width of less than twenty ft, a DSD of less than 40% of the recommended distance for the posted speed limit, a length of thousands of ft, and a traffic flow of tens of thousands of vehicles per day, which are allowed to travel at speeds of forty-five mph or faster. For the 959 rated rockcuts in Tennessee, almost all cuts have ditch widths less than nine ft and about half have DSD's less 40% of the recommended distance. The distribution of the Site and Roadway Geometry score is shown in Fig. 6.

Organization of Final Project Report

This Final Project Report, which describes and documents the implementation, database, field aids and training for the Tennessee Rockfall Management System (RMS), has major subsections as given below (not including these preliminary pages). A brief description is given for each. It should be noted that the Final Report - Phase I is neither duplicated nor superseded by Final Report - Phase II. The two reports should be regarded as major sequential subsections of the overall project documentation. The reports are separate, and both are necessary. Each report has its own executive summary, table of contents, acknowledgments and references.

Final Report - Phase I

This report is a minor update of the Phase I report submitted to TDOT in 2002. The report provides background and motivation for the project, the scope of work, and the methodology to be used for the Tennessee rockfall hazard rating system. It presents the results of the first phase of fieldwork (5 counties only). The report describes the use of TRIMS and the use of the PDA for data collection.

Final Report - Phase II

This report is a minor update of the Phase II report submitted to TDOT In July 2005. The report gives a brief introduction to the project, and then presents the results from the fieldwork carried out in 78 counties across East and middle Tennessee – combining the findings from the second phase of fieldwork (73 counties) with those from the first phase (5 counties). The report presents statistical summaries of the hazard score, the site and roadway geometries score, the geologic character score, the distribution of rockfall mode and the number of modes per site - across the state and by TDOT administrative region. The spatial distribution of rockfall hazard is discussed in the context of regional geology. Finally, there is a discussion of the main factors contributing to high score (high hazard) slopes.

Appendices

Appendix A - Tennessee Rockfall Hazard Rating System (RHRS)

The Tennessee Rockfall Hazard Rating System (RHRS) is described in detail in Appendix A. Both the preliminary and the detailed ratings are discussed. Measurement techniques for parameters are described.

Appendix B - Field Data Collection Sheet (paper)

This is the Paper Field Sheet, versions 1.0 and 1.1.

Appendix C - PDA (Personal Digital Assistant) User Manual

This is the PDA (Personal Digital Assistant) User Manual

Appendix D – Field Training Manual

This is the training manual for identifying geologic failure modes, and assessing abundance of those modes. It includes exercises and solutions.

Appendix E - User Manual (help file) for the Rockfall Database (Access)

This is the User Manual (help file) for the Rockfall Database (Access)

Appendix F - GIS implementation and User Manual

This appendix describes the GIS implementation and serves as the User Manual for accessing and interacting with the rockfall database via a geographic information system (GIS)

Appendix G - Work Load Summary for Field Data Collection

This tabulates the field hours spent collecting rockfall hazard data for the initial implementation of the Tennessee rockfall management system

Appendix H - Electronic Data Collection

This appendix documents the approach used for electronic data collection during this project.

Appendix I - Database Integration

This appendix describes the database integration.

Appendix J - List of Publications

This appendix will comprise a list of all publications, presentations and student theses connected with the Tennessee rockfall project. Complete citations will be given. Electronic copies of these documents will be provided to TDOT.

Appendix K - Pendragon Computer Files

This appendix contains the Pendragon v5 computer files used to provide the necessary functionality to the PDA data collection system.

Appendix L - Field Photograph Library Structure

This appendix contains the field photographs. The field photographs comprise approximately 3 GB and are included on a separate DVD. The directory structure for the field photograph library is shown below. The folders shown in the list below each contain numerous image files.

Region I	Region I\01-Anderson\SR116\001-40L
Region I\01-Anderson	Region I\01-Anderson\SR116\002-00L
Region I\01-Anderson\SR009	Region I\01-Anderson\SR116\002-60L
Region I\01-Anderson\SR061	Region I\01-Anderson\SR116\002-70L
Region I\01-Anderson\SR071	Region I\01-Anderson\SR116\002-80L
Region I\01-Anderson\SR116	Region I\01-Anderson\SR116\003-60L

Region I\01-Anderson\SR116\003-70L

Region I\01-Anderson\SR116\004-50L

Region I\01-Anderson\SR116\005-30L

Region I\01-Anderson\SR116\005-40L

Region I\01-Anderson\SR116\005-50L

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Region I\01-Anderson\SR330\001-60R

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Region I\07-Campbell\SR297

Region I\10-Carter

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Rockfall Management System for Tennessee

Final Report - PHASE I

Submitted to Tennessee Department of Transportation

Division of Materials and Tests

by

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Please note:

This Phase-I final report is a minor update of the final report submitted to TDOT in October 2002

Changes from the October 2002 report are as follows:

1. The appendices have been removed from this report and are now included at the end of the final project report, together with the other appendices.

2. The numbering of the appendices (App. A, App. B, etc) is unchanged. The only difference is that Appendix G now contains information for both Phases I and II.

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Appendices are included at the end of the Final Report.

EXECUTIVE SUMMARY

Rockfall hazard management has historically been reactive rather than proactive. Many states are now moving rapidly towards more proactive philosophies based on recognition of risk and, where necessary, intervention. A vital part of such management schemes is development of a rockfall database that allows systematic identification and prioritization of rock slopes for remediation and/or monitoring. Yet, the broad range of geologic conditions that influence rockfall hazards in most states complicates the development of such systems.

The Rockfall Management System (RMS) developed for the Tennessee DOT includes several features that pertain to data collection, visualization and distribution. In addition to traditional data collection with paper forms, field data such as traffic counts, highway geometry, and geologic characteristics of rock cuts, can be recorded on Personal Digital Assistants (PDA's). The data collection with PDA's allows automatic error checking, and direct synchronization of collected information with the database located on a centralized server. Fields in the PDA are accessed using interactive dropdown menus for consistent and rapid input, and the hazard rating is calculated as the data is collected. Digital photographs, GPS coordinates, and other data are also downloaded into the database. The database is then incorporated into a web-based GIS, which is distributable throughout TDOT. With full implementation, Tennessee's Rockfall Management system should lead to more efficient and economical use of resources, as well as improved safety.

During Phase I of the development of the RMS, rock slopes from five counties were evaluated. The preliminary rating process, conducted using the standard NHI Rockfall Hazard Rating System (RHRS), identified about 80 slopes that required a detailed rating. During the course of the detailed rating, the NHI RHRS was modified. The resulting Tennessee RHRS differs from the NHI system in terms of the methods for rating ditch effectiveness, assessing water flow rather than climate, and classifying potential rock failure behavior (geology). The geological rating was based on the failure mode and characteristics that could be reproducibly measured for each mode. The detailed hazard ratings from the Tennessee system were compared with NHI RHRS ratings. The Tennessee system yielded scores that on average are about 16% greater (greater hazard) than the scores from the NHI system. The water flow vs. climate choice contributed little to the rating difference. Most of this difference in average score is the result of the ditch effectiveness scoring because the Tennessee system more carefully considers the need for effective ditches. The difference in geological scoring is particularly obvious where several failure modes exist in a slope because the Tennessee system scores all modes cumulatively, whereas the NHI system only scores the most hazardous mode. Given that all modes can contribute to hazardous conditions, we believe cumulative scoring to be a wiser choice. Ultimately, while the Tennessee version yields greater scores on average it does not dramatically increase the number of hazardous slopes, but rather lends greater sensitivity to the scoring results by spreading the slopes over a greater scoring range.

FINAL REPORT

1. INTRODUCTION

Failures of rock slopes along Tennessee highways are a frequent problem for the Tennessee Department of Transportation (TDOT) and provide a significant hazard for the motoring public. Rock slope failures occur in many forms, including planar slides, topples, wedge failures, rock falls, and raveling. They can require expensive remediation and at times have resulted in serious injury to motorists (Royster, 1973 and 1979; Moore, 1986). Tennessee has a large number of potentially unstable rock slopes of various lithologies, differing types of failure surfaces, and weathering tendencies. The hazard potential for these slopes is also influenced by such factors as slope height, roadway width, width of ditch area, average vehicle speed, line of sight and number of vehicles per day (NHI, 1993).

Efficient management of rock slopes is essential to most transportation departments. The broad range of conditions related to rock fall hazards, however, can make management quite difficult. For the most part TDOT, like other DOT's, has in the past adopted a reactive approach to slope management. Existing rock fall maintenance problems and catastrophic failures drive the remediation response (Moore, 1986). In contrast, a proactive approach to managing rockfall problems, in which potentially hazardous rock slopes are systematically identified, inventoried, prioritized and remediated, can lead to a more efficient and economical use of resources, as well as improved safety and increased public confidence (Pierson et al., 1990). This need for a systematic way to prioritize rockfall potential has lead to the development of Rockfall Hazard Rating Systems (RHRS) (Pierson et al., 1993), in response to a mandate from the Federal Highways Administration for all states to develop such systems.

This project incorporates a RHRS together with new techniques for field data collection, information management and distribution. The final product will be a comprehensive Rockfall Management System (RMS), which will provide an efficient and robust means to manage rock slopes along Tennessee Highways.

2. BACKGROUND

The Oregon Department of Transportation began developing a Rockfall Hazard Rating System (RHRS) in 1984, based on a hazard rating system previously described by Chuck Brawner and Duncan Wyllie. The term *Rockfall,* in their usage, refers to all kinds of rock slope failures, including rockslides, wedge failures, topples or raveling. Oregon's RHRS was designed as a proactive tool for the efficient management of rock fall sites. It allows Oregon’s DOT to make informed decisions about when, where and how to spend construction and repair funds, and to target high priority (high-risk) areas.

In 1992, the Ontario Ministry of Transportation in Ontario, Canada, began development of the Ontario Rockfall Hazards Rating System (RHRON). Ontario’s system was developed from Oregon’s, with some changes to adapt it to Ontario conditions. For example, in northern Ontario, sliding instabilities were rare in comparison with raveling, toppling and ice jacking. Ontario’s system is based on twenty parameters rather than the twelve used by Oregon. Additional parameters used in Ontario include the height of the emergence of the water table from the rock face, looseness of the face and block size of the rock mass. Ontario’s parameters are rated on a scale from 0 (good) to 9 (bad).

The National Highway Institute developed a RHRS training course in 1993, based on Oregon’s system (National Highway Institute, 1993). The essential steps of the RHRS are a preliminary classification of all potentially hazardous rock slopes as A, B or C (high hazard → low hazard), detailed rating of all “A” slopes, preliminary design and cost estimates for hazardous sections, project identification and development, and annual review and update. The factors used in the Detailed Rock Hazard Rating in the RHRS (see Table 4.1, NHI 1993) include:

Slope Height Ditch Effectiveness
Average Vehicle Risk
Decision Sight Distance
Roadway Width
Geologic Structure
Rock Friction
Differential Erosion
Block Size / Volume of Rockfall per Event
Climate / Presence of Water

The Tennessee Department of Transportation developed an Access database for implementation of the RHRS in Tennessee. This work was done by Vanessa Bateman, Geological Engineer with TDOT's Geotechnical Engineering Section in Nashville, and co-investigator on this project. Although this rockfall database program fully incorporated the RHRS, only very limited field data had been collected. This database was further developed, including the collection of field data in Smith County (Bateman 2002), however the system was not calibrated/adjusted to Tennessee’s geologic, physiographic and climatic conditions.

In September 2000, the University of Tennessee, in collaboration with the Tennessee Department of Transportation, began a research project to develop a **Rockfall Management System (RMS)** for U.S. Routes, State Routes and Interstate Highways throughout Middle and East Tennessee. The RMS will include an enhanced version of the Rockfall Database, easy-to-use digital data entry in the field, integration with a GIS to facilitate management decisions, and the collection of all pertinent engineering and geologic data. Capabilities of the RMS will include built-in error checking, ease of updating and seamless downloads to desktop computers.

3. SCOPE OF WORK

Due to the magnitude of the overall task, the project is divided into two phases:

- PHASE I - a two-year study of rock slopes in five counties, with the goals of developing a Rockfall Hazard Rating System (RHRS) for Tennessee, and developing electronic data collection techniques with GIS integration. Data from the RHRS will be incorporated into the Rockfall Management System (RMS). The initial five counties in Phase 1 were selected to represent the different physiographic and geologic regions in Tennessee.

- PHASE II – a multi-year study to finalize the RMS, implement the RMS along U.S. routes, State Routes and Interstate highways in the remaining counties of East and Middle Tennessee, and training TDOT personnel in the use and maintenance of the RMS.

Figure 1 illustrates the counties in Tennessee surveyed during Phase I and the counties to be investigated during Phase II.

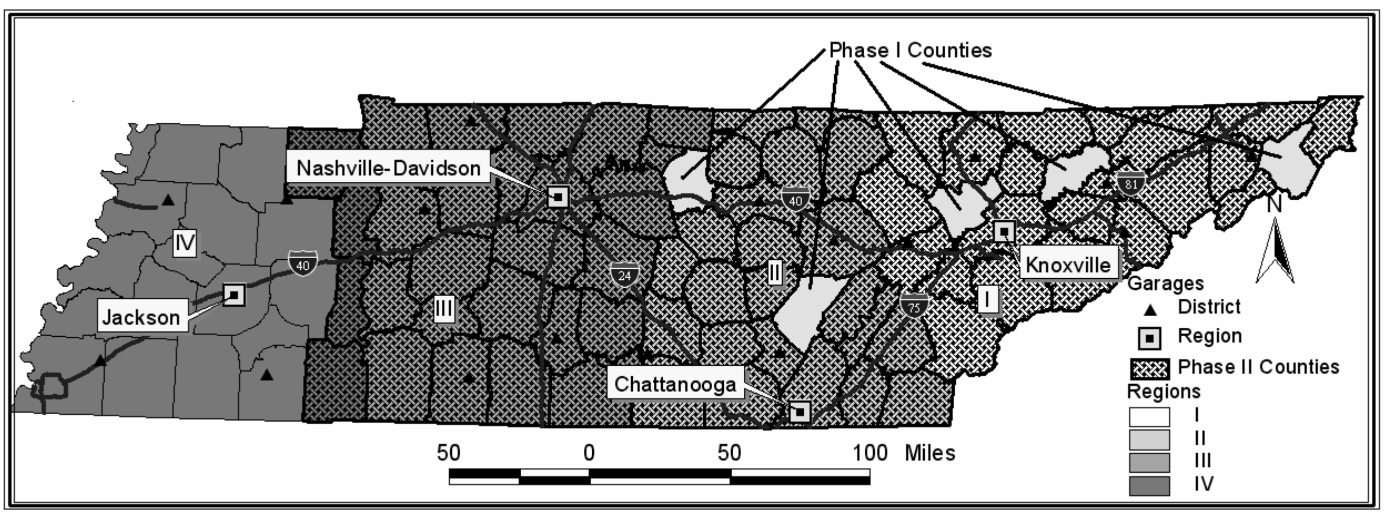

Figure 1. Map of Tennessee illustrating counties to be rated in Phase I and II

4. OVERVIEW OF ROCKFALL MANAGEMENT SYSTEM (RMS) FOR TENNESSEE

The **Rockfall Management System (RMS)** includes a revised Rockfall Database, preliminary and detailed hazard ratings in Middle and East Tennessee with an improved RHRS, electronic field data collection, data integration into a GIS for display, analysis and prioritization of rockfall hazard, and training of TDOT personnel. The RMS system will use the same location referencing system as TRIMS.

Rockfall Hazards in Tennessee

Virtually all potentially hazardous rock slopes in Tennessee occur in the middle and eastern portions of the state. Although slope instabilities sometimes occur on bluffs in west Tennessee, they involve unconsolidated material rather than rocks. This study is therefore confined to middle and east Tennessee (Figure 1). Problems with rock slope hazards occur both along the interstate system, and along primary and secondary state highways. The majority of the problem slopes along Tennessee's interstates, however, have already been identified and remediated, although not inventoried. Rock slopes along the state highway system (primary and secondary) have received less attention.

Rockfall Hazard Rating.

The two main procedural steps in slope hazard rating for this study are as follows.

1. **Preliminary rating and inventory of rock slopes**: Rock slopes are classified initially as A = high hazard, B = moderate hazard or C = low hazard. For slopes classified as A or B, the location is entered into a geographic database, basic data pertaining to the slope (see the RHRS field data sheet, NHI 1993, p. 16) is collected and the slope is photographed. Data are not recorded for slopes classified as C.

2. **Detailed rating of high hazard (A) slopes**: Information is gathered on the rock slopes using an RHRS with modifications for the geologic, geomorphic and climatic conditions in the state of Tennessee. Identified rockfall sites will be prioritized in terms of hazard score.

PDA-based Field Data Collection

PDA's (Personal Digital Assistants such as Palm Pilots, or equivalent) are used to record data in the field through an easy-to-use electronic user interface. Database software is available for PDA's, with most of the functionality of Windows-based database applications such as Access. A PDA program for data entry has been developed for direct import into the Rockfall Database. GPS (Global Positioning System) receivers will be used in the field to record locations for all potentially hazardous rock slopes (ratings of A & B).

PDA-based data collection has several advantages, including:

- Low-cost hardware and software
- Emulates Windows-based database applications
- Easy synchronization with desktop computers
- Elimination of paper forms
- Elimination of office data entry
- Error checking performed in real time in the field
- GPS receivers allow integration with GIS

The electronic data collection and its advantages will be discussed in more detail subsequently.

Integration with GIS

Spatial references (obtained from GPS locations) in the Rockfall Database will allow production of rockfall hazard thematic maps for integration with the TDOT Landslide-GIS. At the conclusion of the project, potential rockfall sites, together with their hazard ratings, as well as links to photographs and other pertinent data, will be viewable as layers in the GIS. The rockfall hazard layer, with associated color-coded hazard ratings, can be superimposed on digital maps showing state and county boundaries, towns, state routes and interstate highways, landslide locations, topographic elevation, etc. In this way, prioritization and maintenance decisions can be made based on economic impact to transportation routes, potential risk to the public, cost of remediation including access and proximity to other A & B sites, and other factors.

5. PHASE I INVESTIGATION

Preliminary Rating

Rock slopes in the initial five counties were first located using TDOT's *Tennessee Roadway Information Management System* (TRIMS), which is an application that allows the user to view road conditions for every one hundredth of a mile along all of Tennessee highways (Figure 2). This system proved invaluable for locating rock slopes prior to commencing fieldwork, and facilitated the efficient scheduling of the fieldwork. Rock slopes were located using TRIMS, and their log miles recorded along with traffic and roadway geometry information. The initial fieldwork involved visiting each slope identified with TRIMS, and assigning a preliminary rating of A, B or C based on the potential for rocks to enter the roadway and present a hazard to motorist. Preliminary ratings were assigned following NHI guidelines (NHI, 1993):

- A – slopes have a moderate-to-high potential for rocks to reach roadway and/or high historical rockfall activity.
- B – slopes have a low-to-moderate potential for rocks to reach roadway and/or moderate historical rockfall activity.
- C – slopes have a negligible-to-low potential for rocks to reach roadway and/or low historical rockfall activity.

Figure 3 shows the results of the preliminary ratings by county for the total numbers of A and B-rated slopes.

Detailed Rating

Following the preliminary rating, a Detailed Rating was performed on A-rated slopes from the Preliminary Rating. The Detailed Rating employed the Tennessee RHRS that characterized these factors:

- Slope height
- Ditch effectiveness
- Average Vehicle Risk (AVR)
- Roadway width
- Percent of Decision site Distance (%DSD)
- Geologic characteristics
    - Structural related failure modes: wedge, planar, and toppling
    - Weathering failure modes: raveling and differential weathering
- Climate and presence of water on slope
- Rockfall History

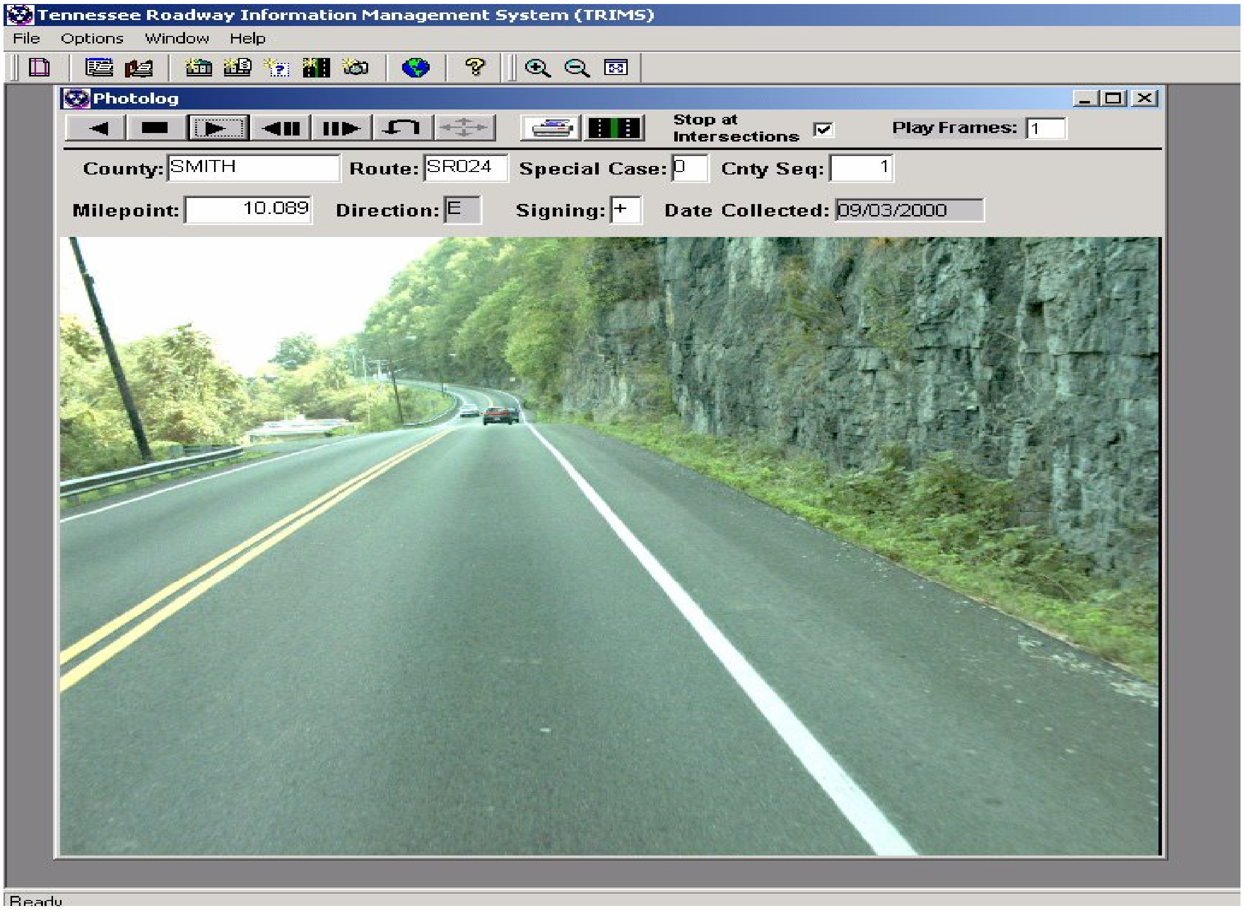

Figure 2. Tennessee Roadway Information Management System (TRIMS) user interface and example screen shot.

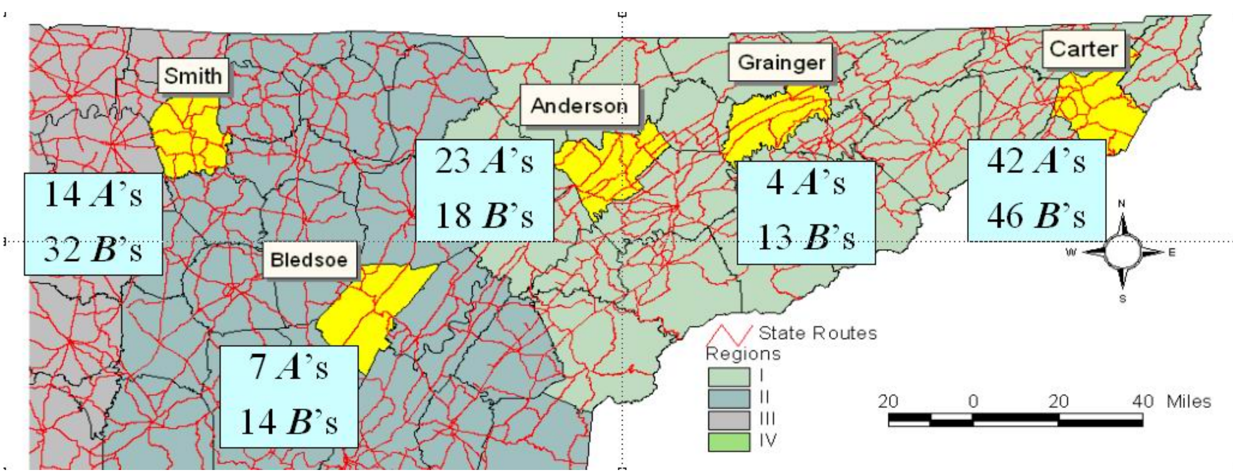

Figure 3. Preliminary ratings by county. Total of 90 A slopes, and 123 B slopes

Most of the above data categories are in the NHI RHRS. Certain categories have been modified, however, to provide more accurate, informative, and reproducible input (Vanderwater, 2002). Appendix A describes the Tennessee RHRS (both the Preliminary and Detailed Rating systems). The paper form used for data collection and field rating aids are included in Appendix B. The measurements used to rate each factor were stored in the Rockfall Database along with location information, and digital photographs.

The rockfall hazard data were collected on both a traditional paper form and using Personal Digital Assistants (PDA). The paper form was used primarily to aid development of the Tennessee adaptation of the RHRS system because form modification was easier in a paper format during fieldwork. The finalized rating system was then implemented into electronic forms on PDA's. Appendix C is a user guide for the PDA version of the data collection form for the Preliminary Rating, and Appendix D is the user guide for the Detailed Rating. The PDA permits direct entry of data into a *PenDragon Forms* database for the Palm™ with a customized input form. This software package mirrors the database maintained on the database server, which is Windows-based desktop workstation or UNIX server. During Phase I, a desktop server was used. *PenDragon* includes a desktop application, which was used to develop the PDA input forms such as shown in Figure 4. Each input form represents one field in the database for a particular rock slope record.

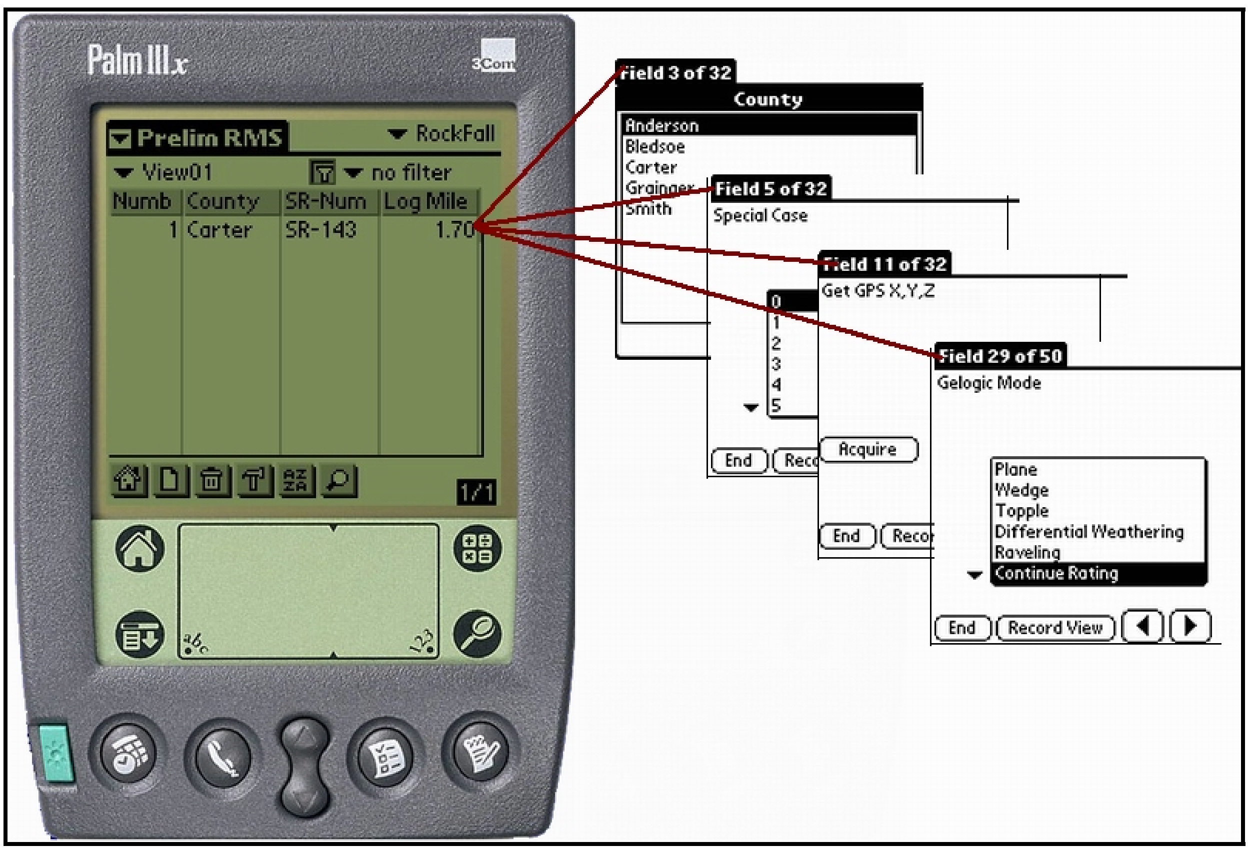

Figure 4. Typical PDA input forms for the Rockfall Hazard Rating System (RHRS).

The forms were developed to provide simple consistent input through the use of drop-down list boxes, check boxes, yes-no selections, and numeric keypad entries. The acquisition of GPS coordinates can be accomplished from a GPS receiver directly attached the PDA (Figure 5) or connected by a serial cable. Alternatively, the GPS coordinates can be entered into the PDA with a numeric keypad. The use of a PDA for data input also automates some of the data entry by using logic that was programmed into the input forms; so that particular input into one form will dictate the input required for subsequent forms. For example, selecting “wedge” as a failure mode brings up forms specifically related to that mode. The program logic within the input forms also provides real-time error checking and calculates the rating for each rock slope before leaving the site. Field calculation of the rating allows field personnel to consider whether the slope was rated correctly, based on the rater’s previous field experience. Appendix D outlines the many advantages of field data collection using PDA’s.

Figure 5. Palm PDA with attached GPS receiver

Information Management with GIS

Information obtained in the field using the PDA is synchronized with a central Access database. *PenDragon*’s desktop program includes tools that handle multiple users, and automatically maintains the latest record sets to ensure only the most recent records are retained in the central database. The database is added to a geographic information system (GIS) as a data warehouse in GeoMedia Professional 4.0 (Intergraph). Additional layers include the state route and interstate networks, counties, cities and TDOT regions.

The GIS allows the user to browse and edit the data. The rockfall information can also be mapped based on any of the measures recorded in the field. Thematic maps, such as that shown in Figure 6 where the RHRS total scores are divided into ranges (larger and darker dots indicate higher hazard ratings) are a convenient means to review the hazard ratings. Thematic maps can also be used to identify counties or state routes with the greatest incidence of rock slopes with high hazard potential (Figure 7). For example, the GIS can be used to determine the number of slopes rated above a certain level per mile of road within each county. Spatial analysis of the different layers viewed in the GIS can also be used to study correlations between hazardous slopes, geology, and topography.

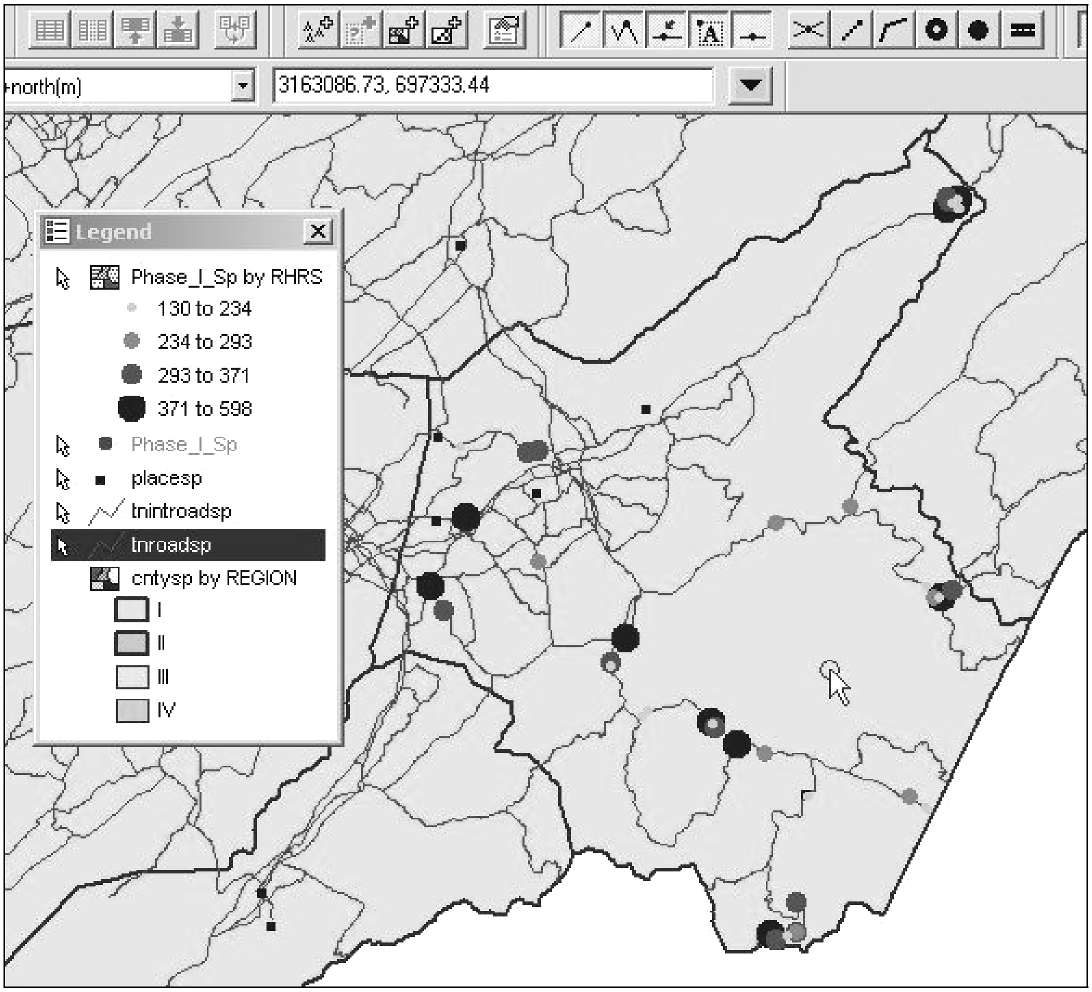

Figure 6. Thematic map in which the RHRS total scores are divided into ranges, where larger and darker dots indicate higher hazard ratings. Thematic maps and other queries may be produced for any of the attributes recorded in the database.

The RMS information is to be made available to TDOT engineers and geologists through a web-based GIS. This system is currently being developed using Intergraph's GeoMedia Web Enterprise 4.0 (GWE) on a Windows 2000 server running Microsoft's Internet Information Server (IIS). The web-based interface is being developed using HTML, Java script and VBScript. The use of Java script and VBScript within Active Server Pages (ASP) provides a robust GIS application with all the necessary functionality of desktop GIS packages, but without their expense. The web-based application allows the user to view rock slope records along with thematic maps, digital photographs, and other layers such as topography and geology. The system also provides a means to link to all electronic documentation related to a particular rock slope, such as geologic reports, rockfall maintenance records, memoranda, field reports, contract information, and remediation design files. All information about a rock slope can then be located and viewed from within one convenient interface.

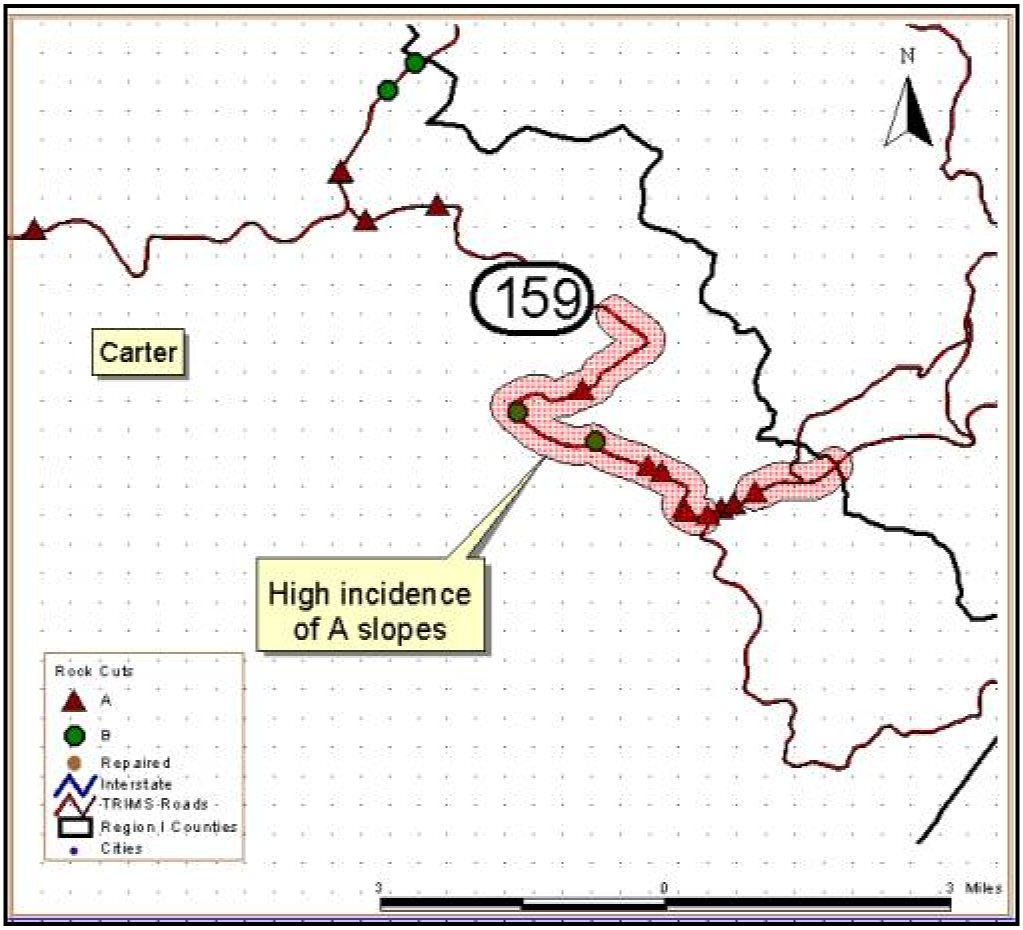

Figure 7. Thematic map produced from the GIS, showing that State Route 159 in Carter County has a high incidence of A rated slopes.

6. SUMMARY OF RESULTS FROM PHASE I DETAILED RATINGS

Each A-rated slope was revisited to perform a Detailed Rating and obtain a hazard score. During the fieldwork, the preliminary rating of some slopes was revised, particularly for a few early-visited slopes, as a result of additional experience gained during later preliminary rating and detailed rating. In Smith and Anderson counties, the number of "A" slopes was reduced, while the number increased in Carter County. The number of "A" slopes was unchanged in Grainger and Bledsoe Counties (Figure 8).

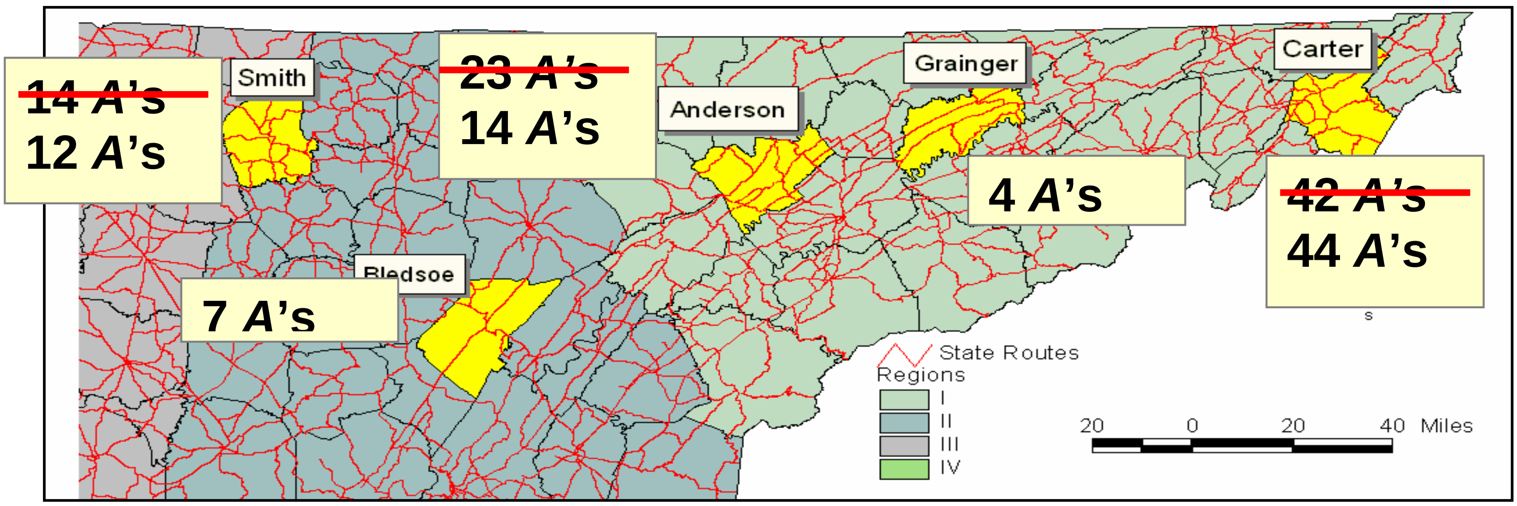

Figure 8. Revised Preliminary Rating after completion of Detailed Ratings. The total number of "A" slopes was reduced from 90 to 81 after the Preliminary Rating

Comparison of Tennessee RHRS and NHI RHRS slope ratings for Phase I slopes

Each "A" rated slopes received a detailed rating, based on the proposed Tennessee RHRS system described in Appendix A. The scores ranged from about 130 to 600, with a mean score of about 300. For comparison, each "A" rated slope was also scored according to the NHI RHRS. On average, the Tennessee RHRS produced scores that are about 15% greater (Figure 9). A perfect correlation between the two systems would have all data falling on the 1:1 line in Figure 9, but while this data arrangement is absent, the NHI +50% line bounds nearly all the Tennessee RHRS scores.

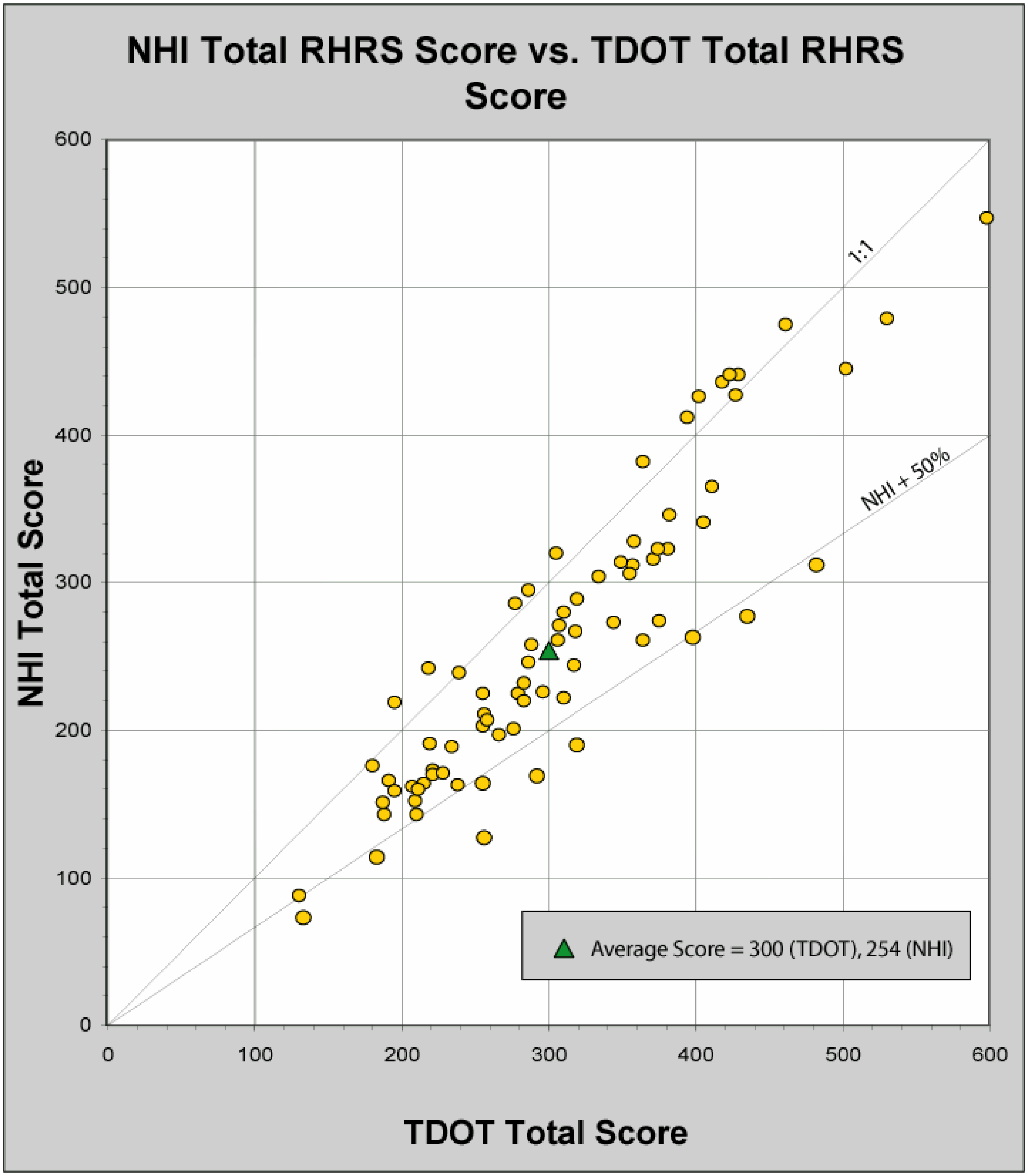

Figure 9. Comparison of scores from NHI and Tennessee Rockfall Hazard Rating Systems

The differences between the Tennessee and NHI scores can be attributed to three primary factors:

- Role of Climate and Presence of Water
- Role of Ditch effective
- Role of multiple geology modes

Each of these are discussed below.

Role of Climate and Presence of Water

In the NHI system, scores are assigned for a combination of climate and presence of water. Since all Tennessee slopes experience nearly the same climate, climate was not considered leaving the variable presence of water that is based on the amount of water observed flowing from the slope as the scoring factor (see Appendix A). The scores for the presence of water yielded a slight increase in the Tennessee score relative to the NHI system for climate and presence of water.

Role of Ditch Effectiveness

Ditch effectiveness is as very important parameter in the rating of slopes for potential rockfall. Slopes that may have a high probability of producing significant amounts of rockfall may not be a significant danger if well-designed ditches are present. In the proposed Tennessee RHRS, the ditch effectiveness score is derived from the percentage of the design ditch width (see Appendix A). The Tennessee scoring method typically produces ditch effectiveness scores that are higher than those using the NHI RHRS. The mean Tennessee ditch effectiveness score is 79, whereas the NHI average is 35. This difference of 44 is shown graphically as a lateral shift in Figure 10, illustrating that the two systems would produce more similar results if this difference is eliminated. Due to the role the ditch plays in keeping rockfall out of the role, we believe that retaining this difference is desirable.

Role of Multiple Geologic modes

In the Tennessee RHRS, multiple failure modes, if present, contribute to the geologic score up to a maximum of 300 points, which is the maximum number of points for geology in the NHI RHRS. In other words, a slope experiencing raveling and the potential for planar failure would accumulate points from both categories, whereas, the NHI system would only generate points for the more hazardous of the two modes. The authors believe that allowing points to accumulate from multiple potential failure modes better represents the rockfall risk associated with slopes possessing multiple modes. This choice is important because 62% of the slopes exhibited more than one potential rockfall mode (Figure 11). If the geologic component of the RHRS score is compared alone (Figure 12), the influence of the additive nature of the multiple geologic modes is more evident, because most slopes with significantly greater Tennessee scores than NHI score (> NHI + 50%) have multiple failure modes. Raveling, in particular, contributed to this effect at a large number of the 62 slopes. This observation is consistent with intuition of TDOT personnel who have felt that raveling is a common failure mode for rockfall that can reach the highway.

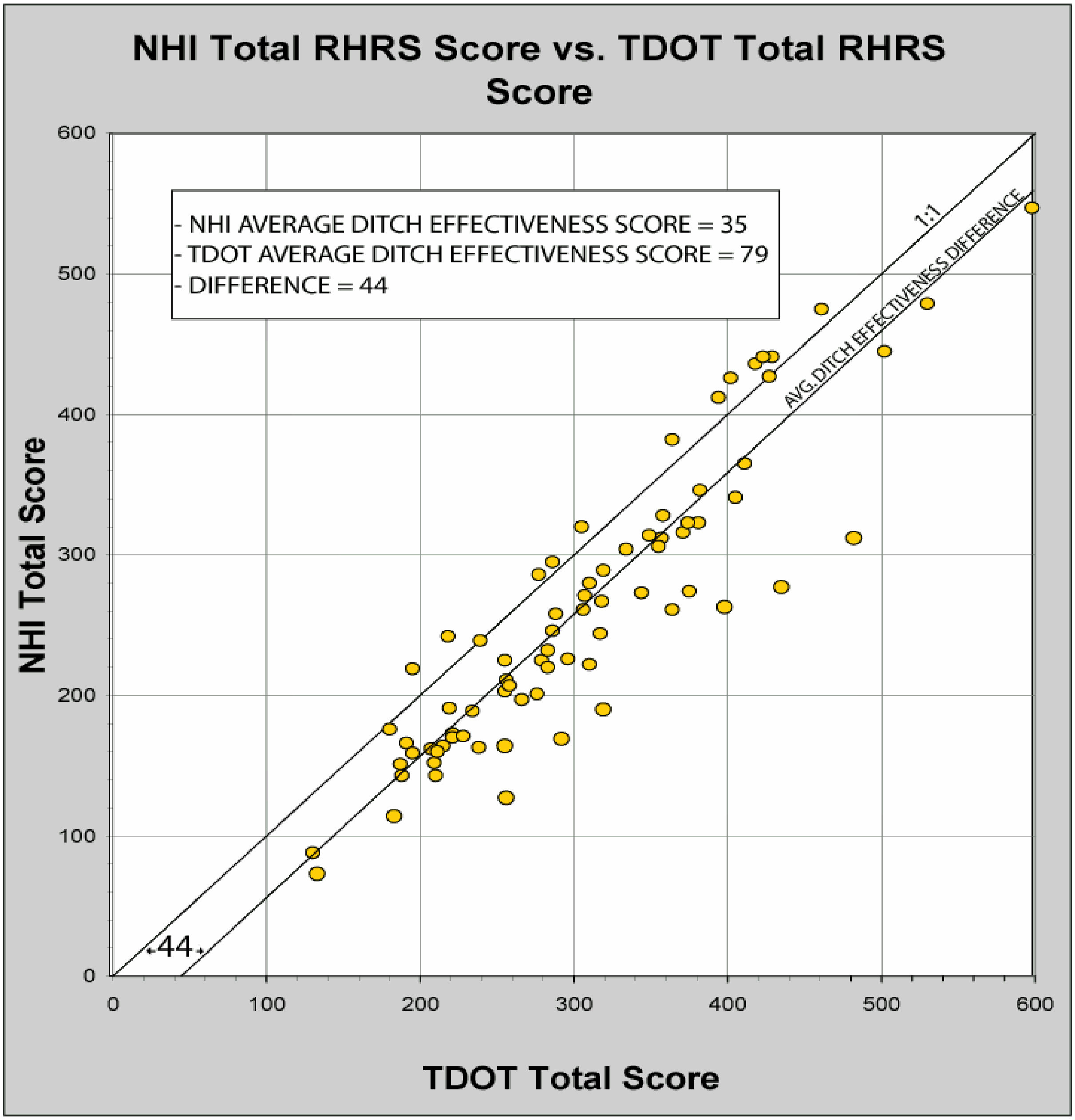

Figure 10. Comparison of NHI and Tennessee RHRS with offset for Ditch Effectiveness score

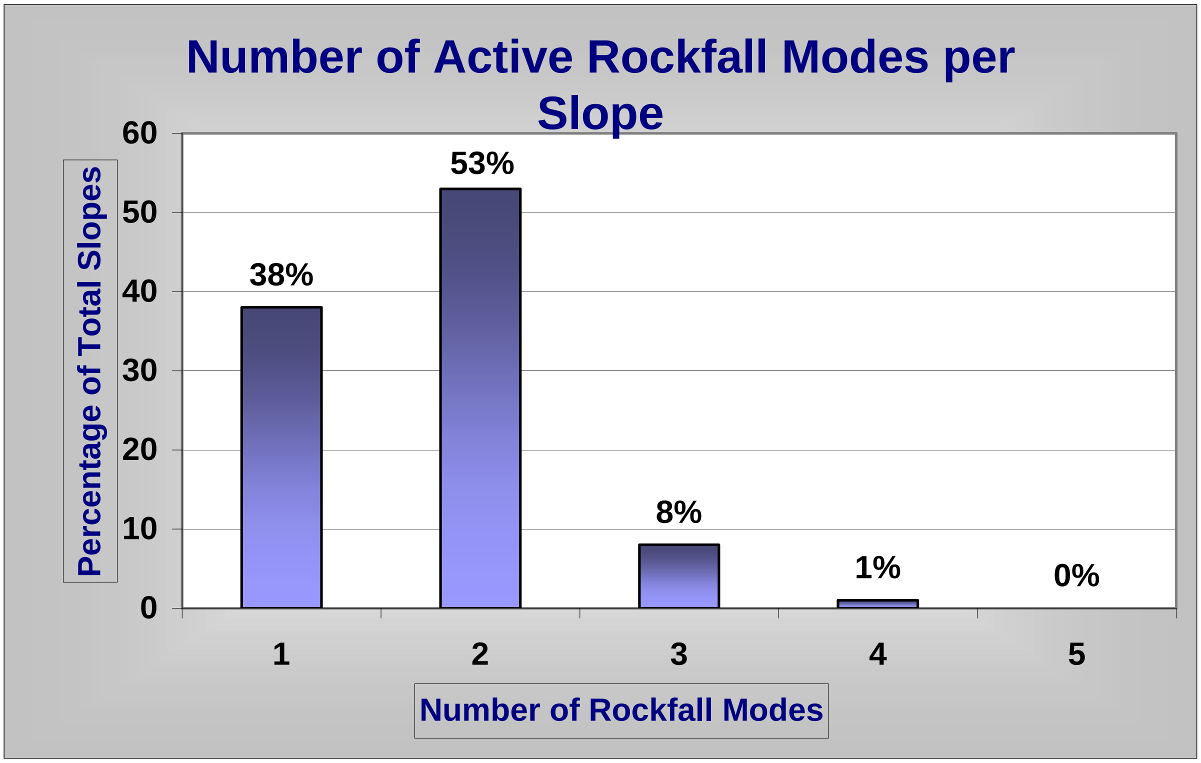

Figure 11. Histogram of the number of rockfall modes observed per slope

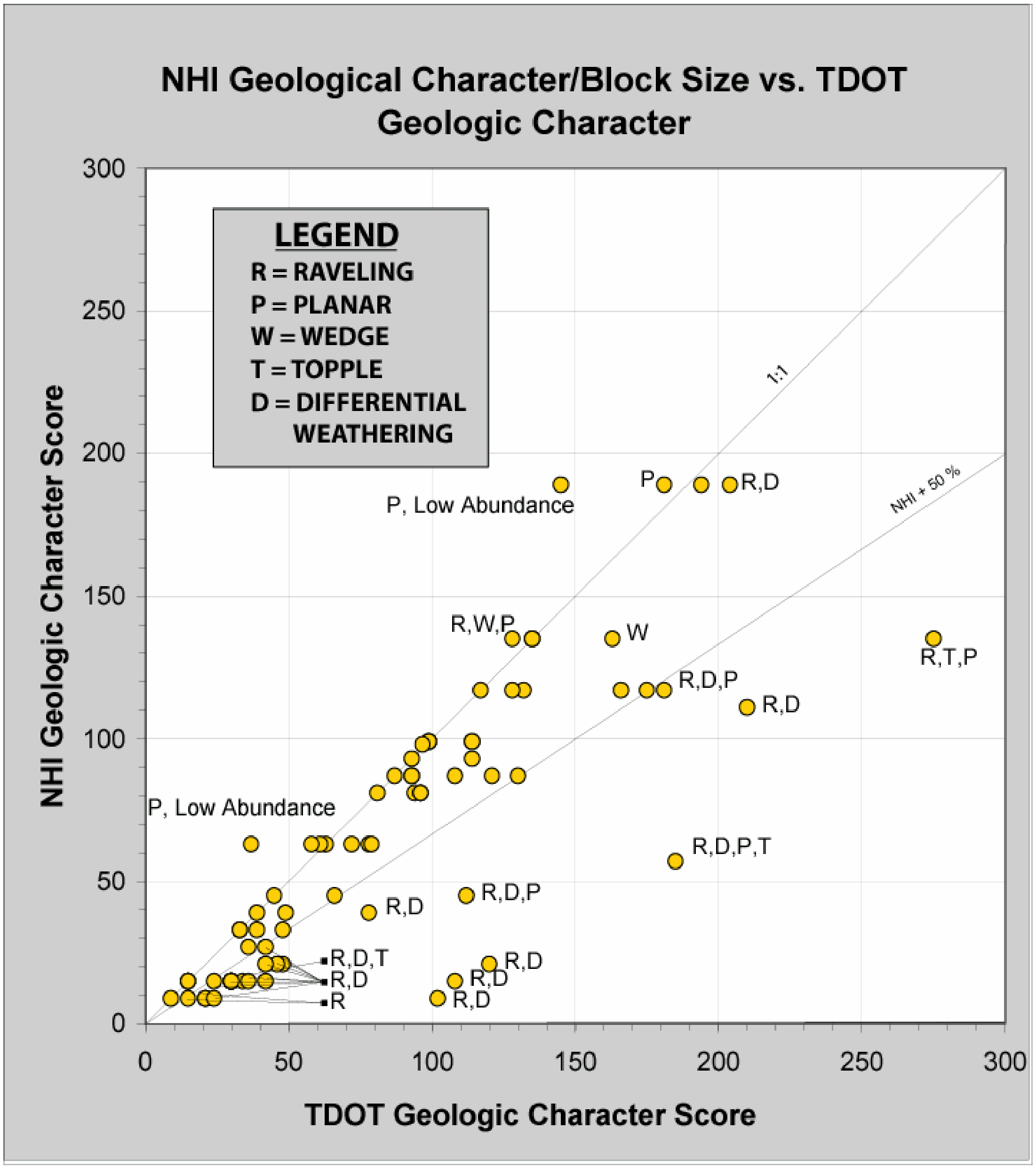

Figure 12. Comparison of NHI Geology Character and Block size scores with Tennessee RHRS Geologic Character scores

7. TRAINING

To facilitate the use of the Tennessee RHRS, a series of training aids and user guides were developed. Appendix A includes a detailed description of the components of the Tennessee Rockfall Hazard Rating System, while Appendix B includes the paper data collection form with figures and tables to aid the field scoring of slopes. PDA user guides for the Preliminary and Detailed ratings are included in Appendix C and D, respectively. Appendix E serves as a user guide for the interim desktop database, while Appendix F describes the implementation of the Tennessee Rockfall Management System in a Geographic Information System (GIS). A summary of the field manpower requirements for Phase I is provided in Appendix G, and a discussion of the advantages of electronic data collection is included as Appendix H.

8. CONCLUSIONS

The Rockfall Management System developed for the Tennessee DOT integrates a customized Rockfall Hazard Rating System, a web-based GIS application, and a Rockfall Database to provide a robust single interface for analyzing rock slope information. The system is intended to be a valuable tool for the proactive management of rock slopes. The most important use of the system will be to identify and prioritize rock slopes with the greatest potential for rockfall to provide decision makers with all the necessary information they need to plan remediation efforts. Over time, the RMS can be used to track costs and effectiveness of different remediation methods used on problem rock slopes.

The information collected at each rock slope are acquired and maintained in electronic format using PDA's. The use of PDA's for field data collection has many advantages such as the elimination office data entry, real time error checking, and the PDA's database application emulates windows-based application with uncomplicated synchronization.

During the pilot implementation of the Tennessee RHRS, five counties selected to be representative of a range of geologic conditions were surveyed. A total of 81 slopes were ultimately identified as category "A" slopes requiring detailed evaluation. Additional field data were collected and the rockfall scores obtained using the Tennessee RHRS were compared with the scores from the NHI RHRS. The Tennessee RHRS focuses on water flow rather than climate because flow unlike climate varies significantly across the state, uses a more rational method for calculating ditch effectiveness, and characterizes geologic attributes using failure modes. These differences tend to lead to more reproducible scores. In general, the Tennessee RHRS produces scores that are on average 16% greater than NHI RHRS scores, but better characterizes the importance of ditches and the causes of geologic attributes, while still distinguishing high scoring slopes from low scoring slopes.

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Rockfall Management System for Tennessee

Final Report - PHASE II

Submitted to Tennessee Department of Transportation

Division of Materials and Tests

by

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July 2005

Please note:

This Phase-II final report is a minor update of the final report submitted to TDOT in July 2005

Changes from the July 2005 report are as follows:

1. The title page has been modified for consistency between the Phase-I and Phase-II Reports

2. The original July 2005 report had one appendix: Appendix A. Appendix A (manpower usage) has been removed from this report and included as Appendix G of the final report, together with the other Appendices. Because the original report did not explicitly reference Appendix A, no further changes in the document are necessary

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Executive Summary

Rockfall hazard management has historically been reactive rather than proactive. Many states are now moving rapidly towards more proactive philosophies, using field rating systems often based on the Rockfall Hazard Rating System (RHRS) developed by the National Highway Institute, which allows systematic identification and prioritization of rockcuts for remediation and/or monitoring. In October 2000, the Tennessee DOT began Phase I of the development of a Rockfall Management System (RMS) for these purposes. A RHRS was developed for Tennessee (TRHRS) that included a more explicit description of the geologic modes likely to contribute to rockfall and a demonstration of the rating system through an investigation of rockcuts in five counties. Field data were collected digitally through the use of Personal Digital Assistants (PDA's), after development of a paper form for data collection. In October 2002, Phase II of the project began. This phase included the collection of TRHRS data in the remaining seventy-three counties identified by TDOT, and the implementation of a GIS system. The web-based Geographic Information System (GIS) will allow for display, analysis and prioritization of rockfall hazards and is to be a key component of the RMS. This report presents the field data collected during Phases I and II, and a second report late in 2005 will describe the integration of these data into the GIS-based Rockfall Management System.

Acknowledgements

The investigators wish to acknowledge the many people who contributed to the completion of the field work throughout Phase II of this project. From the University of Tennessee, the summer 2004 and 2005 field work crews included Frank Dworak, James Everett, Philip Gray, Lori McDowell, Adam Milam, Diana Miller, Matt Osbourne, Chad Philips, and Aaron Short, and in 2005 Chris Beall assisted with the data analysis. From Virginia Tech, the summer 2004 and 2005 field crews included Aaron Antell, Sam Cain, and Brett Rose. From TDOT, Vanessa Bateman and Harry Moore contributed substantially to this area of project design and discussion of implementation, and the traffic control crews in Districts 15 and 21 provided a safe work environment.

Chapter 1 – Introduction

Rockcut failures along Tennessee highways are a recurring problem for the Tennessee Department of Transportation as well as a hazard for the motoring public. These failures require removal or costly stabilization treatments, and at times have resulted in serious injury to motorists (Moore, 1986). Tennessee has a large number of potentially unstable rock slopes of various rock lithologies, discontinuity characteristics, degrees of weathering, and topographic profiles. These potentially unstable slopes exist adjacent to both major transportation routes and adjacent to rural roads. Potential hazards to the public from unstable rockcuts depends additionally on site and roadway geometry factors such as slope height, width of catchment, roadway width, line of sight, average vehicle speed, and number of vehicles per day.

Efficient management of rockcuts in Tennessee is difficult, largely as a result of the broad range of conditions related to rockfall hazards. The Tennessee Department of Transportation, like most state DOT’s, has thus far adopted a reactive approach to management of rock slope hazards. Potential rockcut stability problems along existing highways are identified and remediated in response to existing rockfall maintenance problems or to the occurrence of catastrophic failures (Moore, 1986). A proactive approach to managing rockfall problems, in which problem areas are systematically identified, inventoried, prioritized and remediated, should lead to more efficient and economical use of resources, as well as improved safety and increased confidence of the public (Pierson et al., 1990). Experience gained in Oregon from previous research funded by the Federal Highway Administration and several other states led to development of a Rockfall Hazard Rating System (RHRS). During this period (mid-80's) the Federal Highway Administration (FHWA) mandated rockfall hazard rating systems for all states. As a result, the National Highway Institute (NHI) offers a course about the RHRS (NHI Course No. SA-93-057) (National Highway Institute, 1993)

Project History

The Tennessee Department of Transportation developed an Access database for implementation of the RHRS in Tennessee. This work by Vanessa Bateman of TDOT's Geotechnical Engineering Section in Nashville and co-investigator on this project produced the Rockfall Database 2.0. (Bateman, 2002).

In October 2000, a research project was initiated to develop a Rockfall Management System (RMS) for U.S. Routes, State Routes and Interstate Highways in Tennessee. Project goals included preliminary and detailed rockfall hazard rating for the rockcuts in Tennessee, enhancements to the existing Rockfall Database, and data integration into a web-based Geographic Information System (GIS) to allow for display, analysis and prioritization of rockfall hazards. Additional components included the ability to collect field data using Personal Digital Assistants (PDA's) and training of TDOT personnel in the collection of field data and the use of the GIS. The Tennessee RMS was demonstrated during Phase I in a pilot study, based on data collected from five counties **(**Anderson, Bledsoe, Carter, Grainger, and Smith). During the pilot study, the NHI RHRS was modified to create the TRHRS to improve characterization of the role of ditch width, to allow reproducible field evaluation of rockfall history at a rockcut as maintenance records are frequently not easy to access, and to improve geologic characterization by explicitly recognizing potential rockfall modes, incorporating the abundance of a mode at a rockcut as a measured characteristic, and cumulatively including the scores for all potential rockfall modes at a rockcut. A detailed report was provided to TDOT concerning the results of the pilot study (Drumm et al. 2002).

The second phase of the research started in October 2002 with a project completion date of September 30, 2005. In this phase, the rockfall ratings were completed for the remaining seventy-three counties (Figure 1-1). This report presents TRHRS data and highlights some initial conclusions from data analysis. Additional analysis will be conducted when the GIS portion of the RMS is fully developed because the GIS framework will enable a more efficient ability to investigate spatial and population characteristics. The results of the GIS implementation and a spatial analysis of the rockfall ratings will be provided in the second part of the final report, to be prepared near the project conclusion in October 2005.

Rockfall Hazard Rating System

The Tennessee rockfall hazard rating system (TRHRS) produces a score or rating for potential rockfall hazards on interstates and primary and secondary state highways. The two main procedural steps in the rating are:

1) Preliminary rating and inventory of rockcuts, rockcuts are classified initially as A = high hazard, B = moderate hazard or C = low hazard. For cuts classified as "A" or "B", the location is entered into a geographic database and the cut is photographed. Data are not recorded for cuts classified as "C".

2) Detailed ratings of high hazard "A" cuts, for which specific additional field data are collected about the cuts. The parameters include factors related to the traffic level, roadway/rockcut geometry, and geological characteristics. These data are used to calculate a rockfall hazard rating for a rockcut. Details of the field data and scoring are described in Drumm et al. (2002). The detailed rating scores aspects of a rockcut: a) Site and Roadway Geometry that yields a score based on features such as decision sight distance, speed, ADT, slope height, and ditch width; and b) Geologic Characteristics that identifies potential rockfall modes, and scores them each for characteristics including abundance as a percent area of the cut face, size of potential rockfall blocks, steepness and friction of structural discontinuities, and relief of overhanging rocks.

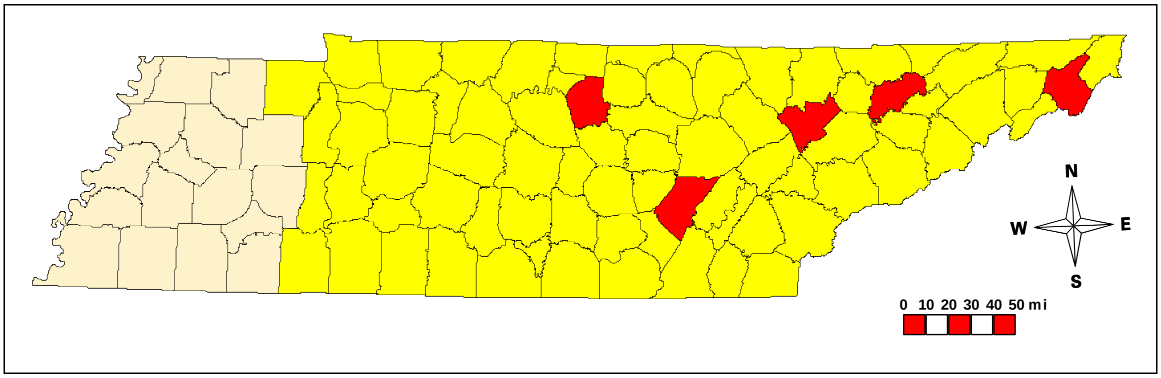

Figure 1-1: Map of Tennessee Illustrating Counties Rated during Phase I (Red) and those Rated during Phase II (Yellow)

Chapter 2 – Field Work Results

Statewide Overview

Phase II of the TRHRS project included the completion of field work in seventy-three counties across the state. The field work was divided between the University of Tennessee and Virginia Tech (sixty-two for UT and eleven for VT) and when combined with the five counties from Phase I yield a total of seventy-eight counties with TRHRS data (Figure 2-1). The results discussed here include the results for all seventy-eight counties (Figure 2-1, Table 2-1).

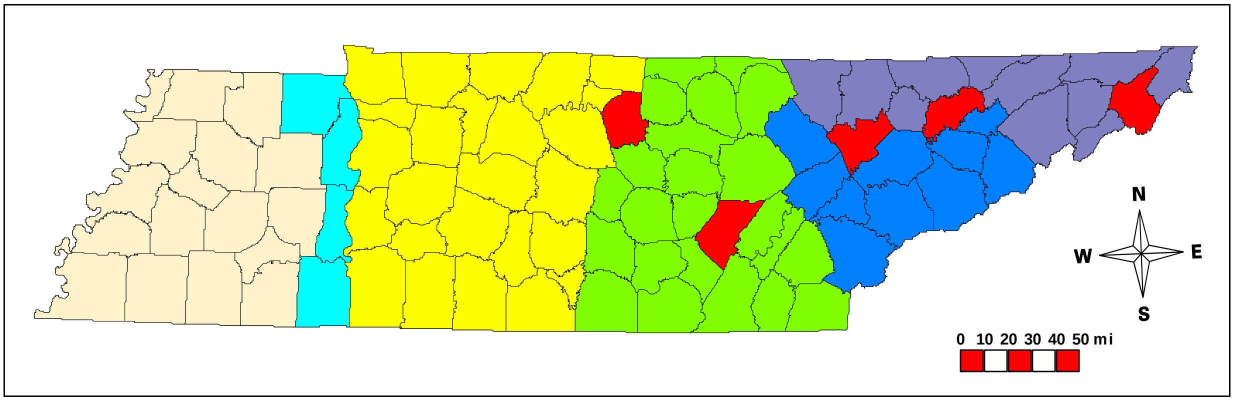

Figure 2-1: TRHRS Field Work Responsibilities Map.

Map Legend:

	Phase I - UT
	Region I - VT
	Region I - UT
	Region II - UT
	Region III - UT
	Region IV - UT

Table 2-1: Total Rockcuts Rated and Scored

Region	"A" Rated Cuts	"B" Rated Cuts	% "A"	% "B"	Total Cuts Rated	Avg. S&RW Score	Avg. Geology Score	Avg. TRHRS Score
I	581	637	48%	52%	1218	192	103	296
II	278	154	64%	36%	432	196	149	345
III	90	194	32%	68%	284	182	96	278
IV	2	1	67%	33%	3	142	69	211
Total	951	986	49%	51%	1937	192	116	308

Note: Average TRHRS score may differ from the sum of average S&RW score and average Geology score due to round off.

The summary data in Table 2-1 does not reflect the results from 12 rock cuts (9 from Davison County, and 1 each from Fentriss, Hamilton, and Knox counties) that were rated as "A" cuts but not scored because of traffic or construction issues. Thus, the total number of "A" cuts identified in all regions is 963, but the subsequent analysis will be based on the 951 cuts that were actually scored.

Statewide, 951 "A" rated cuts and 986 "B" rated cuts were identified. Region I has the greatest number of "A" and "B" rated cuts of any region (581), but Region II has a greater ratio of "A" to "B" cuts. Of the 951 "A" rated cuts, the average score is 308 with a minimum of 113 and a maximum of 792. Twenty-five percent of these cuts score 350 points or higher and only twelve percent score 400 or higher (Figure 2-2). Note that the percentages indicated in Figure 2-2 and subsequent frequency histograms may not total 100 percent due to round off.

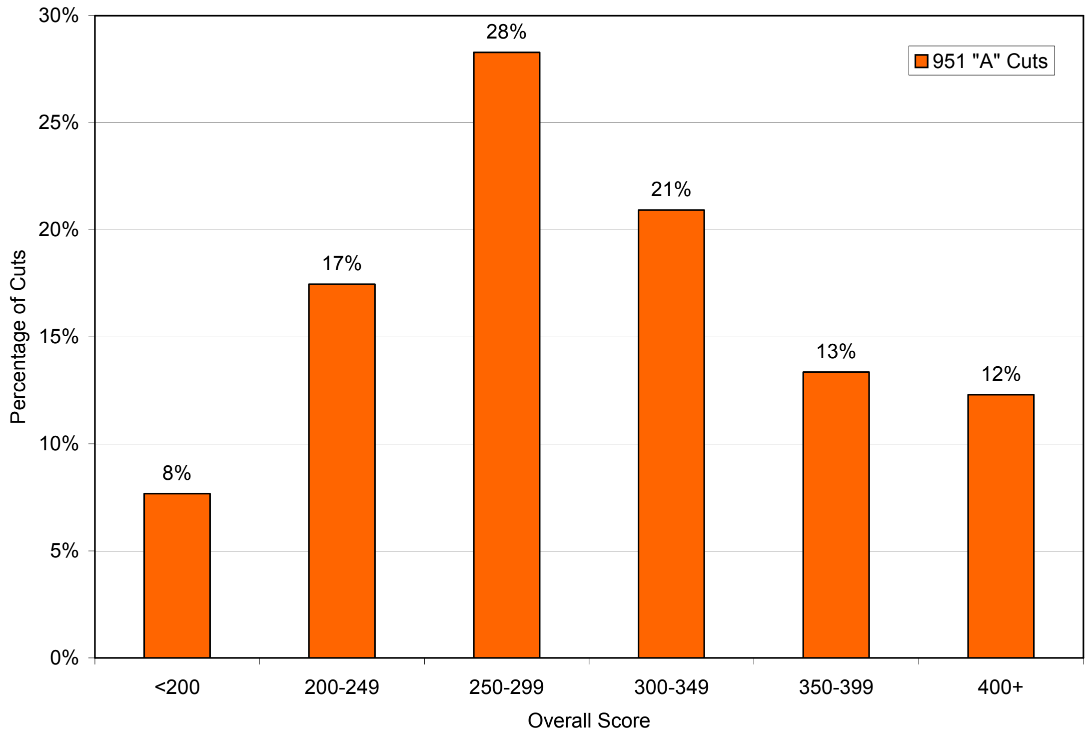

Figure 2-2: Statewide Overall Score Distribution

Site and Roadway Geometry score

The Site and Roadway Geometry sub-score is totaled from the ratings of five characteristics: ditch effectiveness, decision sight distance (DSD), average vehicle risk (AVR), road width, and slope height. Site and Roadway Geometry contributes roughly two-thirds of the overall score with an average of 192 and fifty percent of the cuts scoring greater than 200 (Figure 2-3).

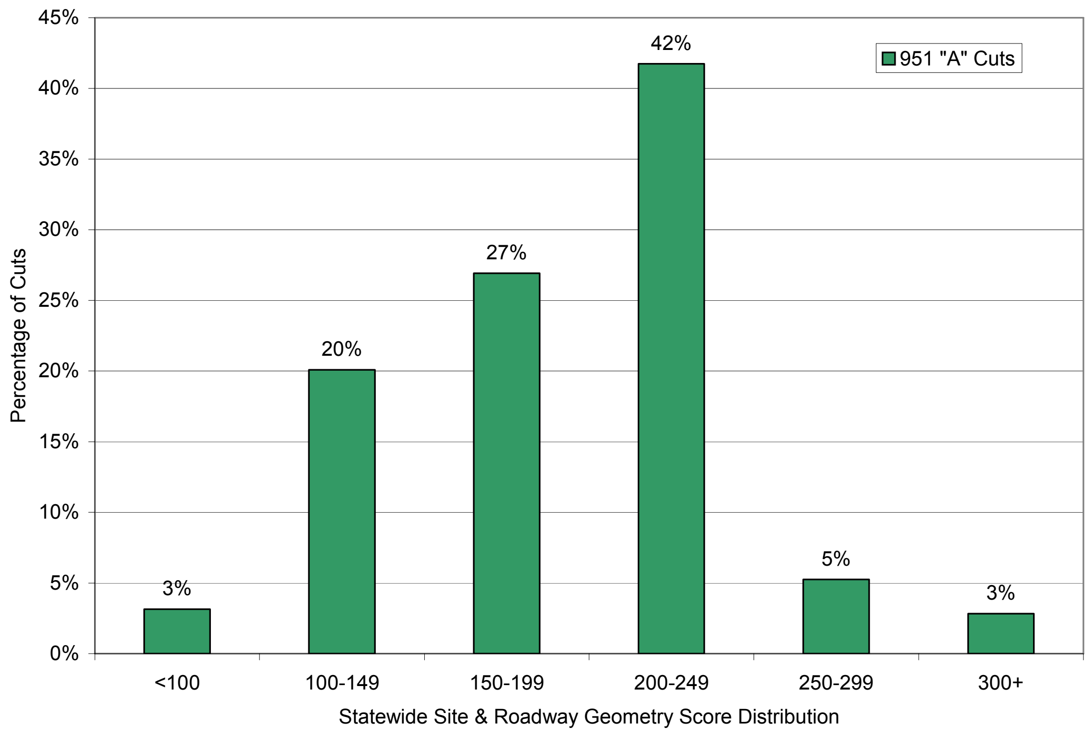

Figure 2-3: Statewide Site & Roadway Geometry Score Distribution

To reach a maximum score in all Site and Roadway Geometry categories, a rockcut would have a height of 100 feet, have a ditch less than nine feet wide, have a road width of less than twenty feet, a DSD of less than forty percent of the recommended distance for the posted speed limit, and have a length in thousands of feet with a traffic flow of tens of thousands of vehicles per day that are allowed to travel at speeds of forty-five mph or faster. For the 959 rated rockcuts in Tennessee, almost all cuts have ditch widths of less than nine feet and about half have DSD's of less 40% of the recommended distance, whereas the other three characteristics typically do not yield maximum scores (Figure 2-4).

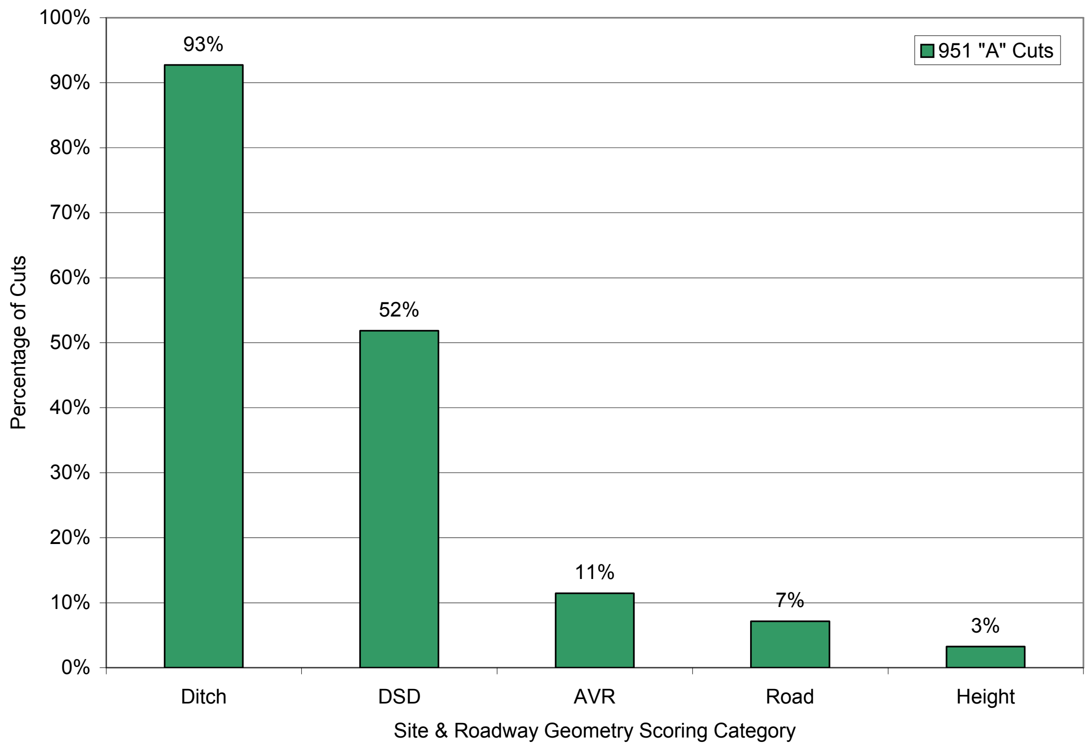

Figure 2-4: Site & Roadway Geometry Categories Receiving Maximum Scores

Geologic Characteristic score

Five potential rockfall modes contribute to the Geologic Character sub-score: planar, wedge, topple, differential weathering (DW), and raveling. Planar rockfall mode occurs when bedding is dipping toward the road and blocks are released and slide along a single rock surface toward the roadway. Wedge rockfall mode occurs much the same as planar rockfall with the exception that sliding takes place along two or more intersecting surfaces. The traditional topple rockfall mode requires discontinuities that dip steeply into the rock face producing blocks that fail by rotating of block out of the cut face and then falling into the road (Norrish and Wyllie, 1996). The bedding-plane release mode, which is treated as topple mode in the TRHRS, occurs in relatively horizontal bedding when blocks of the same lithology fail in tension across bedding or cross-bedding, releasing from the bed above. The differential weathering rockfall mode occurs in layered rocks with two or more different lithologies, and one lithology preferentially weathers out creating overhangs of the more resistant lithologies from which blocks fall. Raveling rockfall mode is defined as the small blocks produced from blasting damage and also from localized, almost random behaviors that do not fit into the other four categories.

Geologic Character contributes roughly one-third of the overall score with an average of 116 and only eleven percent scoring greater than 200 (Figure 2-5). Of the five Geologic Character modes, raveling is the most prevalent with almost a universal occurrence (Figure 2-6). The other modes are less abundant because the necessary geologic conditions for their presence have restricted occurrence within the state. The structural planar and wedge modes are the least abundant because the necessary inclined discontinuities for sliding failure are only common in the eastern part of the state. Toppling would have had a similar restricted occurrence, if only the traditional topple mode was considered. However, the bedding-plane release mode increases the occurrence of topple mode. In Tennessee, the "A" rated cuts most commonly have one or two potential rockfall modes present (Figure 2-7).

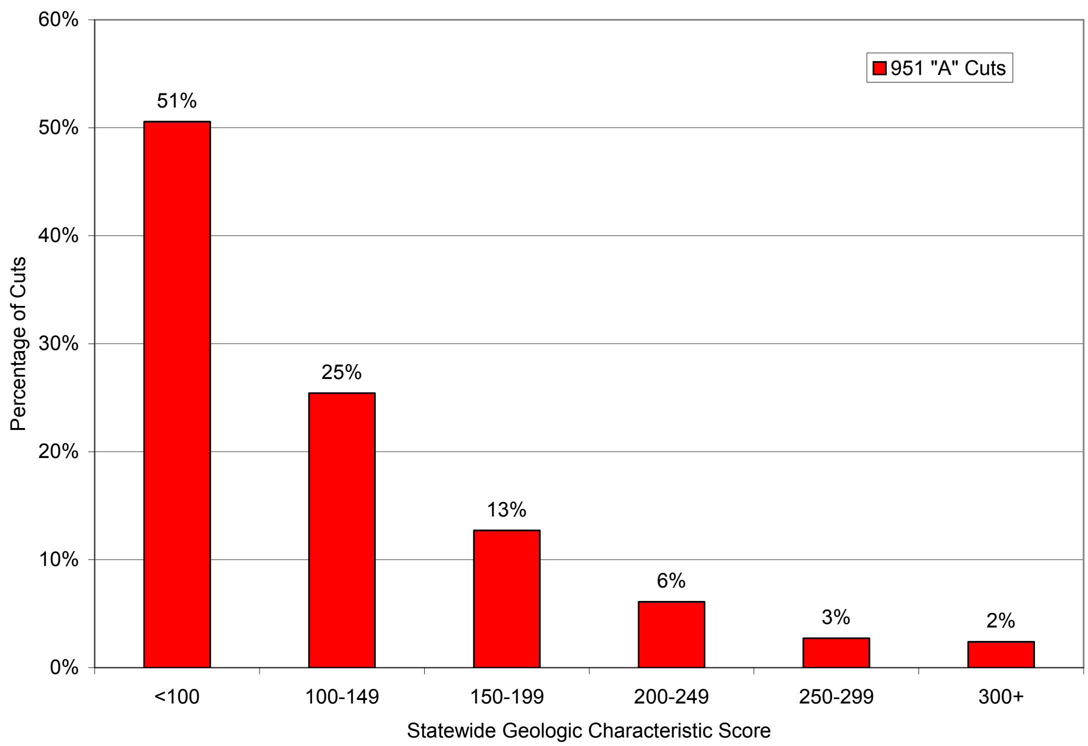

Figure 2-5: Statewide Geologic Character Score Distribution

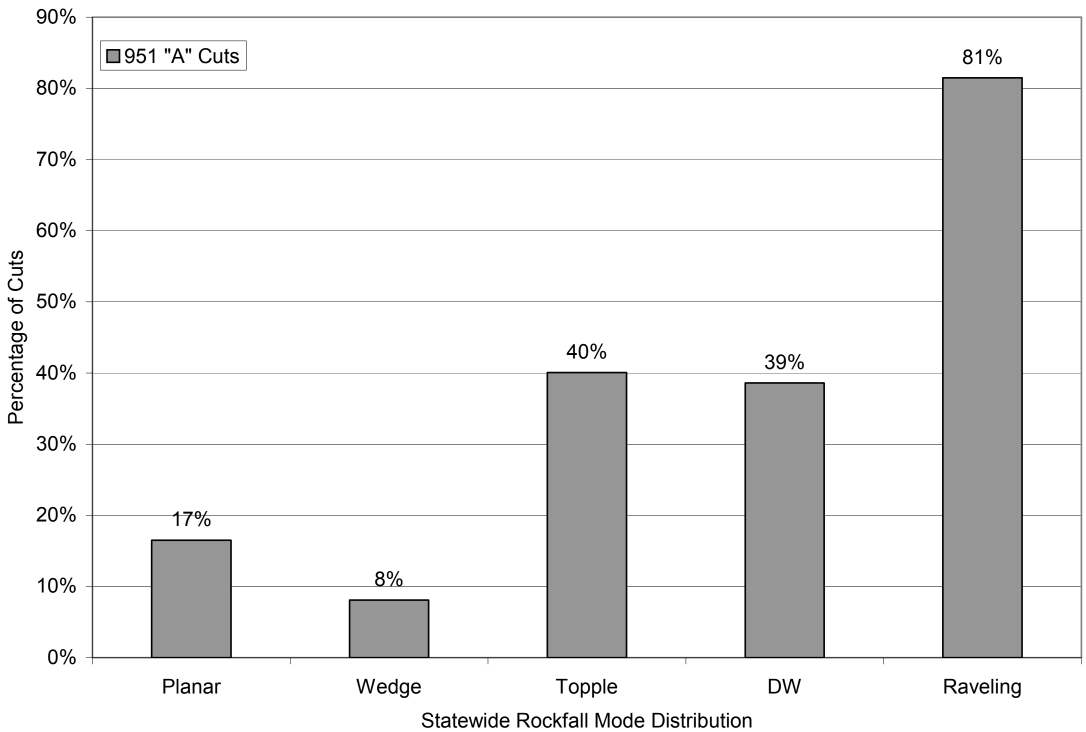

Figure 2-6: Statewide Rockfall Mode Distribution

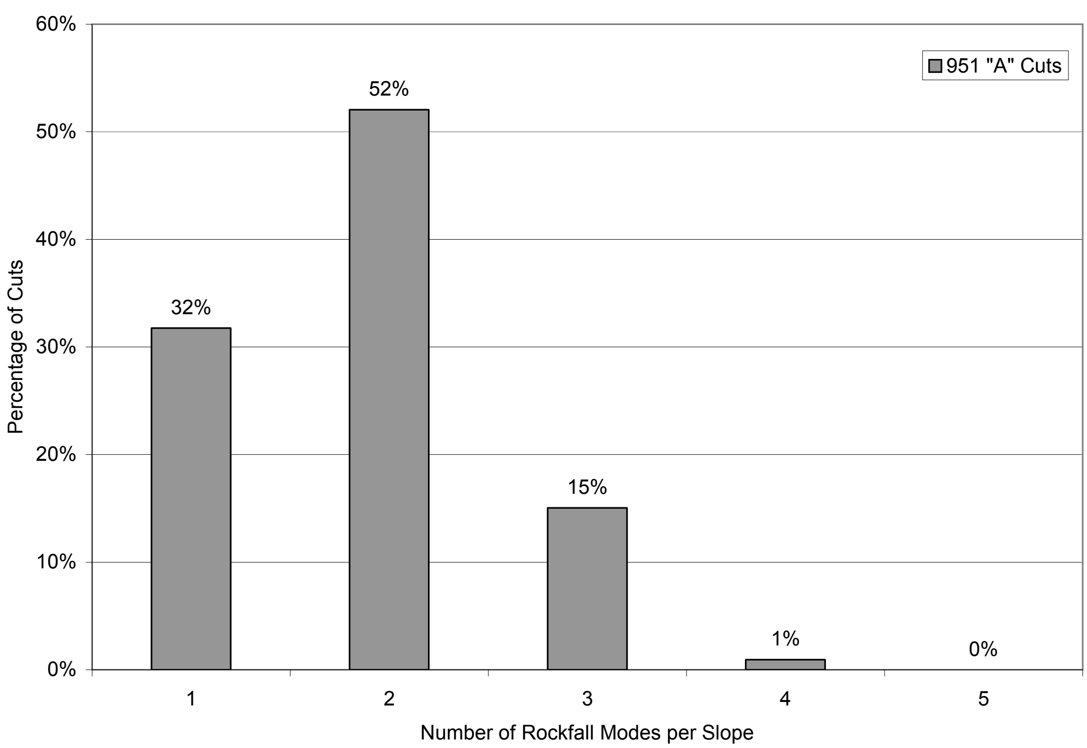

Figure 2-7: Number of Rockfall Modes per Slope

Regional Analysis

Region I has the highest number of rated rockcuts with 1218 (Table 2-1). The average TRHRS score for the "A" cuts in this region is 296 with a Site and Roadway Geometry average sub-score of 192 and Geologic Character average sub-score of 103. The areas with the highest concentration of cuts are the counties along the eastern border of the state including Monroe, Blount, Sevier, Cocke, Unicoi, Carter, and Johnson. These counties account for over two thirds of the cuts in this region, and are all partially or entirely located in the Blue Ridge physiographic and geologic provinces (Figure 2-8). These locations have the combination of topographic relief, resistant rock types and numerous rock discontinuities. Due to a modest population and limited finances for roadway construction, several of the major roads are narrow and/or sinuous with narrow ditches adjacent to tall, geologically hazardous rockcuts.

Planar and wedge rockfall modes (Figures 2-9 and 2-10) occur almost exclusively in this region, with topple and ravel also prevalent. Although Region I has the highest number of hazardous slopes, Region II has the highest scoring rockcuts.

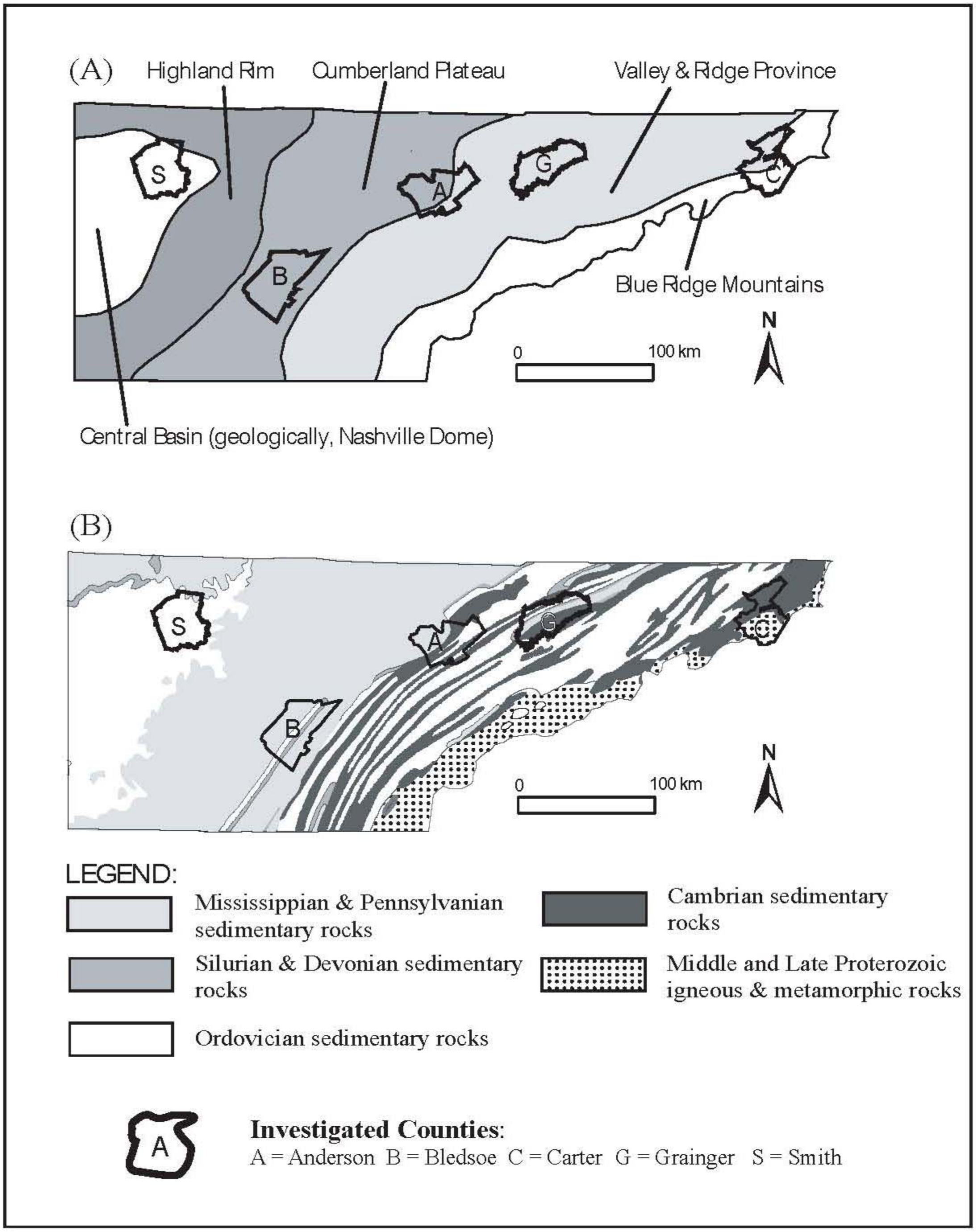

Figure 2-8: Physiographic (A) and Geologic (B) maps of Central and Eastern Tennessee

Figure 2-9:
Planar Rockfall Mode:
Blount County SR115, mile 14.6 right

Figure 2-10:
Wedge Rockfall Mode:
Carter County SR-37, mile 14.1 right

Region II has the second highest number of cuts with 432 (Table 2-1). The average TRHRS score for this region is 345 with an average Site and Roadway Geometry sub-score of 196, and an average Geologic Character sub-score of 149. This region has the greatest concentration of "A" rated cuts with an almost 2:1 ratio of "A" to "B" rated rockcuts and yields the largest scoring cuts in the state. These high-scoring cuts are found at several locations in Region II. Polk County contains State Route 40 through the Ocoee River Valley, which has forty-three "A" cuts in sixteen miles with and average TRHRS score of 417, giving it the greatest density of high-scoring cuts anywhere in the state. Marion and Grundy Counties contain the Monteagle Mountain corridor of Interstate 24, which has an active rockfall history, regularly producing large rockslides. Also, Jackson, DeKalb, Bledsoe, and Hamilton counties contain several high scoring cuts.

Unlike Region I, the setting for these high-scoring cuts is not simple. The Ocoee cuts in Polk County are similar to Region I in that they occur in the Blue Ridge province where the rock has been folded, faulted and partially metamorphosed. Block sizes may range from small to over six feet and several of the cuts are steeply dipping towards the road. Due to the folds and faults in the region, the rock structure at particular cuts may change noticeably. However, Jackson, Marion, and Grundy are located in and on the edges of the Cumberland Plateau. Here the cuts are generally long, straight, exceptionally tall, and produce large block sizes. These larger blocks result from medium to thick bedded sedimentary rocks with near horizontal bedding. Differential weathering plays a much larger role in these counties as rock type in any particular cut may contain limestones, shales, and/or sandstones. Also contributing to the problem in these counties are joints in the rock that in conjunction with the differential weathering and cut face orientation may contribute to a toppling (bedding-plane release) failure. The cuts in Bledsoe County result from the resistant rocks located on the steep flanks of the Sequatchie Valley, whereas in Hamilton and DeKalb Counties geologic history of river incision into resistant rocks created the relief for the hazardous cuts. Toppling, differential weathering, and raveling are common rockfall modes in this region. Planar and wedge failures have a limited occurrence along the plateau and mountainous areas of Region II. Rock failure modes found in Region II are shown in Figures 2-11 and 2-12.

Figure 2-11:
Toppling and Differential Weathering Rockfall Modes:
Sequatchie County SR008, mile 21.2 right

Figure 2-12:
Topple and Raveling Rockfall Modes:
Jackson County SR135, mile 15.5 left

Along with having the greatest concentration of “A” rated cuts and the highest average score, Region II also has the greatest number of cuts that score over 400 with sixty percent of such cuts. Even though Region I has the greatest number of A-rated cuts by region, Region II is the most potentially hazardous region in the state.

Region III has 90 A-rated cuts (Table 2-1) with an average score of 278, a Site and Roadway Geometry average sub-score of 182, and Geologic Character average sub-score of 96. This region has the lowest concentration of “A” rated cuts by region with about a 3:1 ratio of “B” to “A” rated cuts. Davidson County accounts for almost half of the total cuts in the region and about half of the “A” cuts.. This result is primarily due to the greater number of roads with narrow catchments and higher traffic volume in the Nashville area. Because Region III is located in the Nashville Dome, the rock bedding is relatively flat and many rockcuts typically have two or more lithologies including easily weathered mudstone (Figures 2-13 and 2-14). Therefore, differential weathering and raveling are abundant throughout the region with limited occurrence of bedding-plane release form of toppling.

Figure 2-13:
Differential Weathering and Raveling Rockfall Modes:
Cheatham County SR070, mile 4.6 left

Figure 2-14:
Differential Weathering and Toppling Rockfall Modes:
Davidson County SR001, mile 2.4 left

Region IV has the fewest number of cuts in the state by region with 3, where two are “A” rated cuts and one is a “B” rated cut (Table 2-1). These three cuts are all located in Decatur County on State Route 100 (Figure 2-15). Because this region is in the western portion of the state but not adjacent to the Mississippi River Valley, topographic height and relief are small, greatly restricting the number of potential rockcuts. Typical failure modes for this region are differential weathering and raveling (Figure 2-16). These three Region IV cuts are combined with the Region III data for presentation purposes for the remainder of this section.

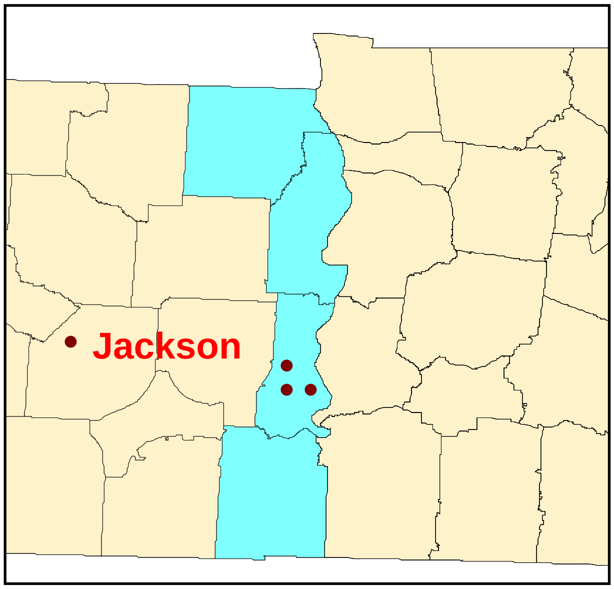

Figure 2-15: Map Showing Cuts in Region IV

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Figure 2-16:
Raveling Rockfall Mode:
Decatur County SR100, mile 9.95 right

With over 60% of the "A" rated cuts, Region I total TRHRS score distributions are similar to the statewide population of TRHRS score distribution (Figure 2-17). In modest contrast, Region II shows a skew to higher scores reflecting the large number of hazardous settings in Region II, whereas Region III/IV skews to lower scores reflecting the modest contribution of geologic characteristics and DSD to scores in these regions.

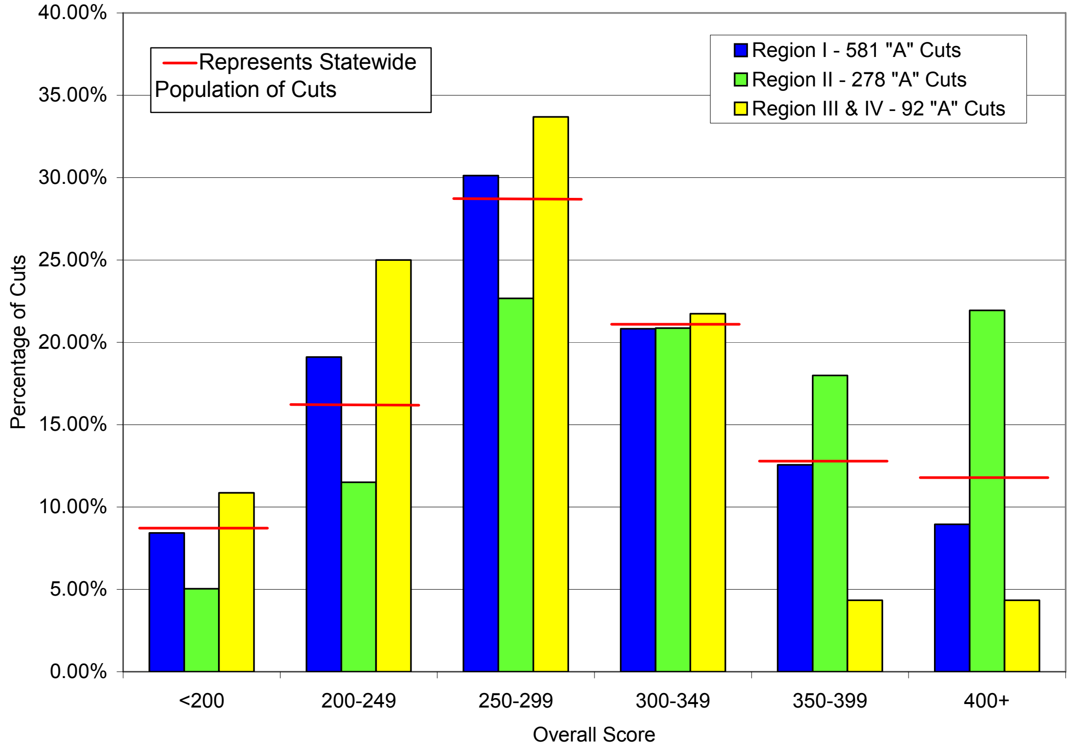

Figure 2-17: Overall Score Distribution by Region

The regional Site and Roadway Geometry score distribution (Figure 2-18), shows that Regions I and II have very similar distributions to each other and the statewide distribution, while Regions III and IV are skewed to lower scores reflecting roads in Regions III and IV that are straighter and provide better rock catchment than those in Regions I and II. The regional Geologic Character score distribution for Region I is similar to the statewide distribution (Figure 2-19). In contrast, Region II scores are skewed to higher values than the statewide distribution reflecting the greater geologic contribution to TRHRS scores in the region, and particularly as a result of the abundant high-scoring cuts in the region. In contrast, Region III/IV is modestly skewed to lower values, reflecting a more modest role for geologic parameters for rockfall hazard in these regions.

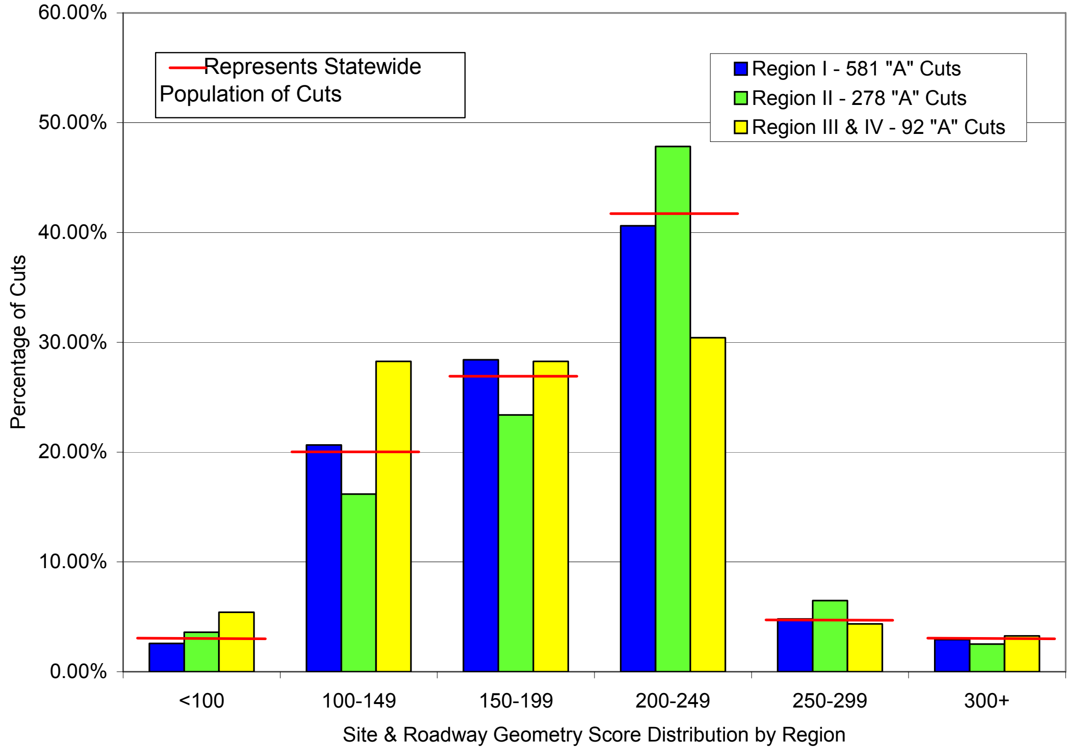

Figure 2-18: Site & Roadway Geometry Score Distribution by Region

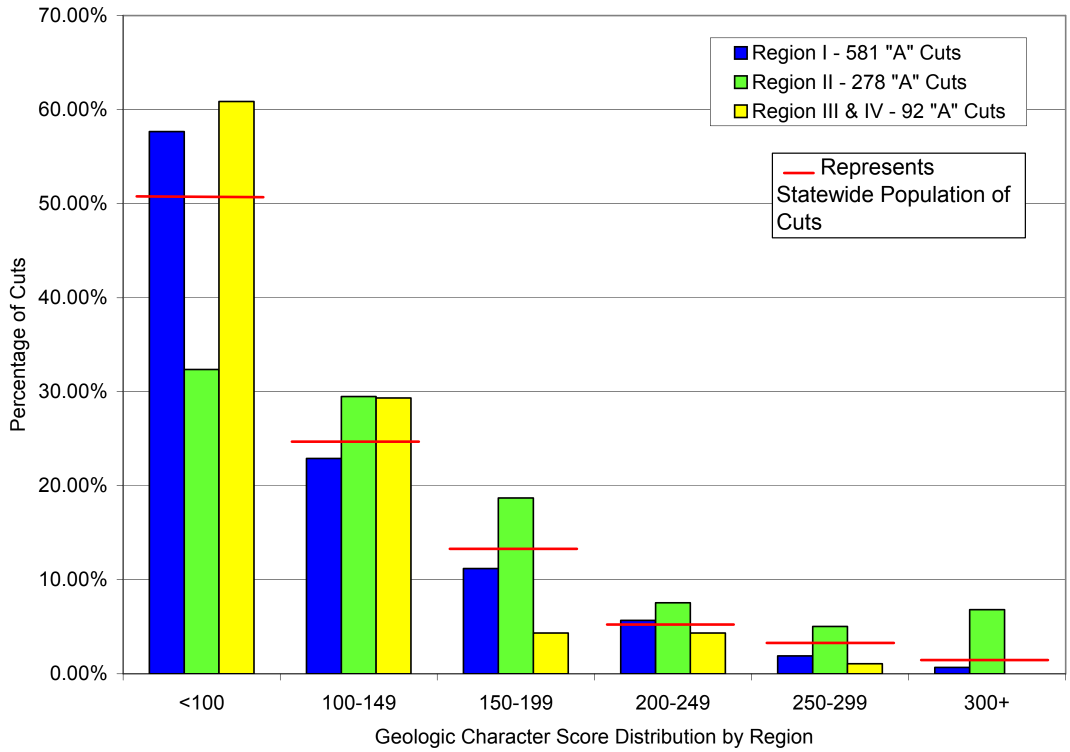

Figure 2-19: Geologic Character Score Distribution by Region

The distribution of rockfall mode varies greatly with each individual region. Region I contains the highest abundance of planar and wedge rockcuts but has the lowest abundance of differential weathering, while Region II has relatively abundant topple and differential weathering. Regions III and IV have no planar or wedge rockcuts and the highest abundance of differential weathering (Figure 2-20).

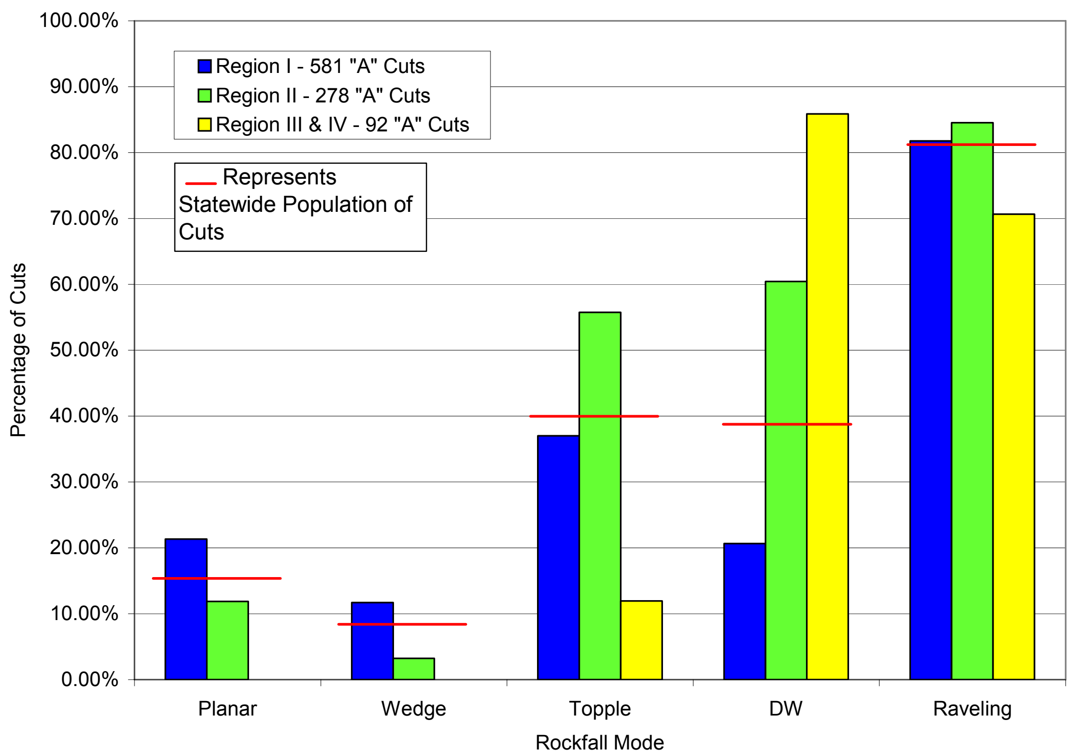

Figure 2-20: Rockfall Mode distribution by Region

“A” Rated Cuts Receiving Scores 400 and Above

Of the total number of “A” cuts identified, there are 117 cuts, or about twelve percent (Figure 2-2), with an overall score of 400 points or more. These cuts represent the greatest potential hazard from rockfall among rockcuts in the state and should reasonably be considered the highest priority for remediation purposes. The majority of cuts scoring 400 or more are found in Polk, Blount, Sevier, Jackson, Hamilton, Hamilton, Monroe, Cocke, and Marion Counties. A wide range of rockfall modes are associated with these cuts as illustrated in Figures 2-21, 2-22 and 2-23.

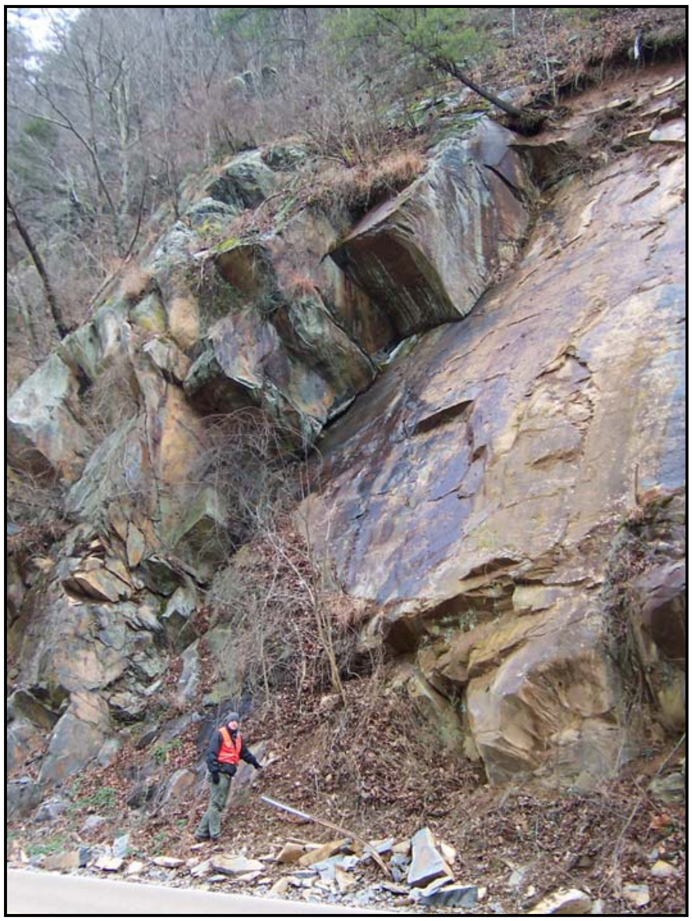

Figure 2-21:
Planar Rockfall Mode: Polk County SR040, mile 14.0 left
Overall Score – 512

Figure 2-22:
Topple and Raveling Rockfall Modes:
Hamilton County SR008, mile 16.0 right
Overall Score – 708

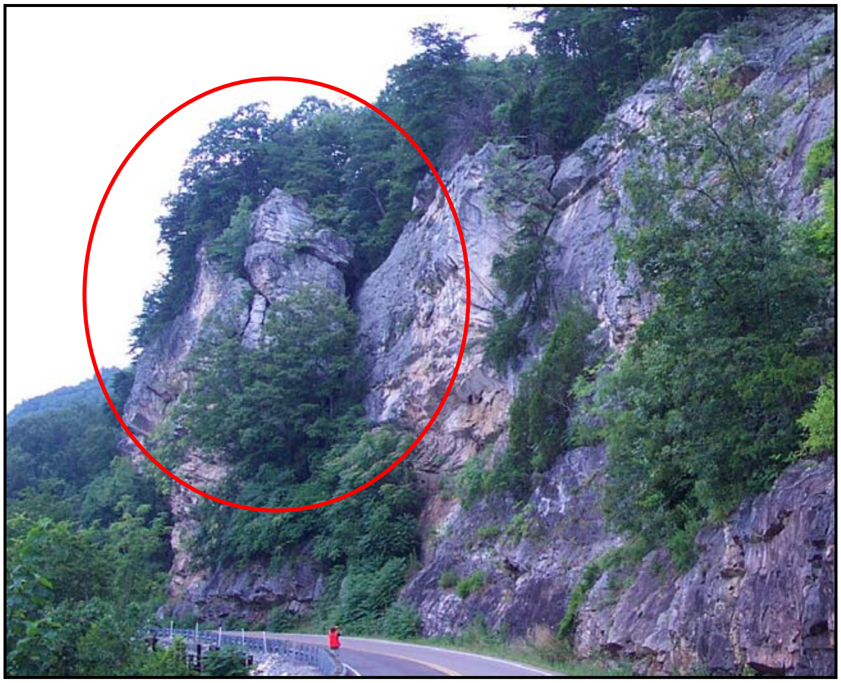

Figure 2-23:
Toppling and Raveling Rockfall Modes:
Bledsoe County SR030, mile 7.4 right
Overall Score – 590

For rockcuts with composite scores of 400 or more, the Geologic Character sub-score contributes nearly half of the total score (48 percent, Figure 2-24), unlike for the entire population of roadcuts where it only contributes only a little more than a third (Table 2.1). Consequently, for these high scoring cuts, large TRHRS scores are not typically generated by Site and Roadway Geometry sub-scores alone and the role of geologic factors is more significant. Regardless of score, the Site and Roadway Geometry characteristics that are the greatest contributors are typically Ditch Effectiveness and DSD, (Figure 2-25). However, for the cuts scoring 400 and above, maximum scores for DSD, AVR, and slope height are 15 to 20 percent more common than for the population of all cuts. These results indicate that the highest scoring cuts will typically have shorter DSD's, greater length, more traffic and greater height than the statewide population of rockcuts.

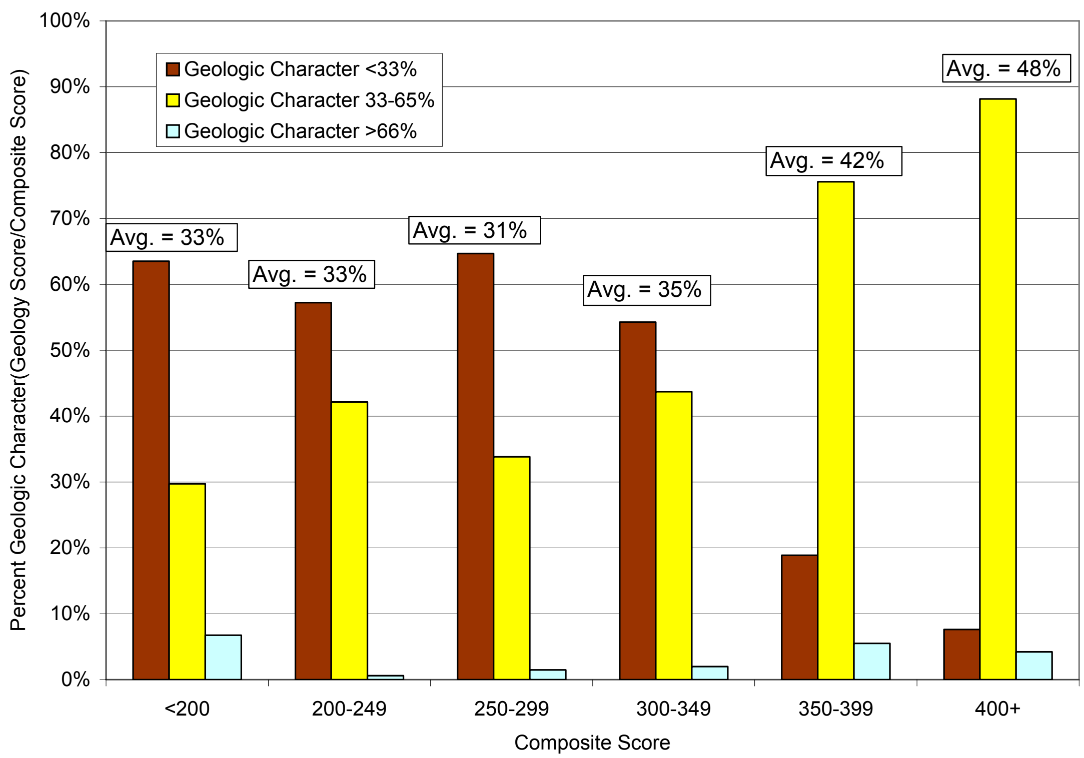

Figure 2-24: Geologic Character as a Percentage of Overall Score

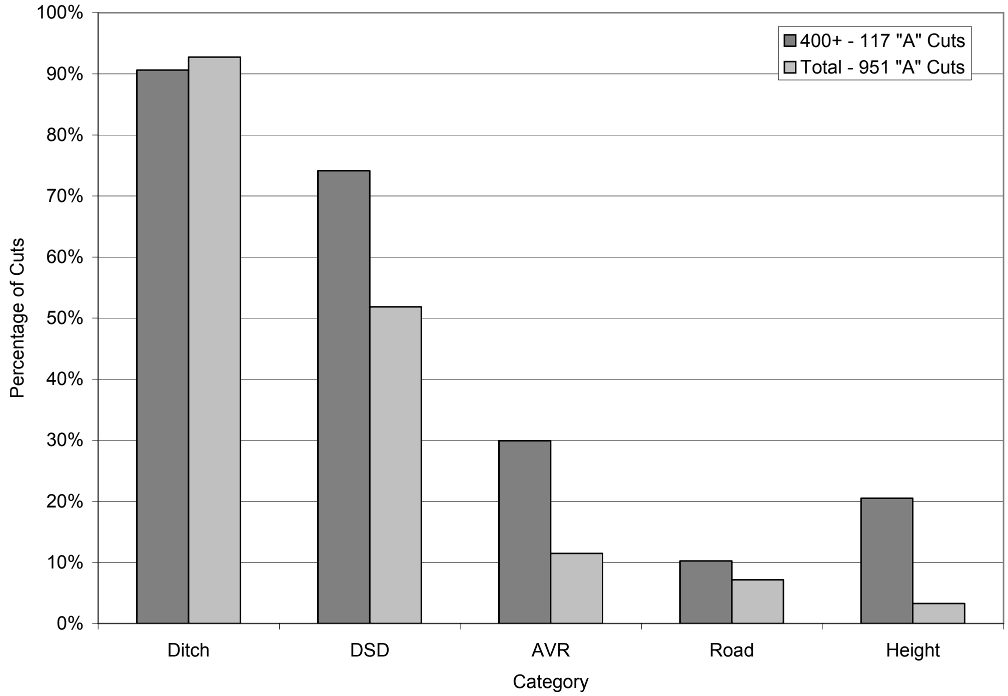

Figure 2-25: Site & Roadway Geometry Categories Receiving the Maximum Score of 81 - Cuts Scoring 400 and Above and the Total Population of Cuts

Another contributor to these large overall scores is an increase in Geologic Character sub-score, because of an increase in structural modes and an increase in the number of modes per cut. Planar and topple modes in the 400 and above cuts are about 20 and 30% more abundant than in the total population of cuts (Figure 2-26). As greater block size correlates to structural failure modes based on analysis of slopes in the Phase I counties (Vandewater et al., 2005), the greater occurrence of structural modes in the 400 and above scoring population favors higher Geologic Characteristic sub-scores as a result of greater block size. Likewise, as the TRHRS accrues cumulative rockfall mode scores, a greater number of modes would generally favor higher Geologic Characteristic sub-scores. Such is the situation as the common number of rockfall modes per rockcut shifts from one or two modes for the entire population to two or three modes for cuts with scores of 400 or more (Figure 2-27).

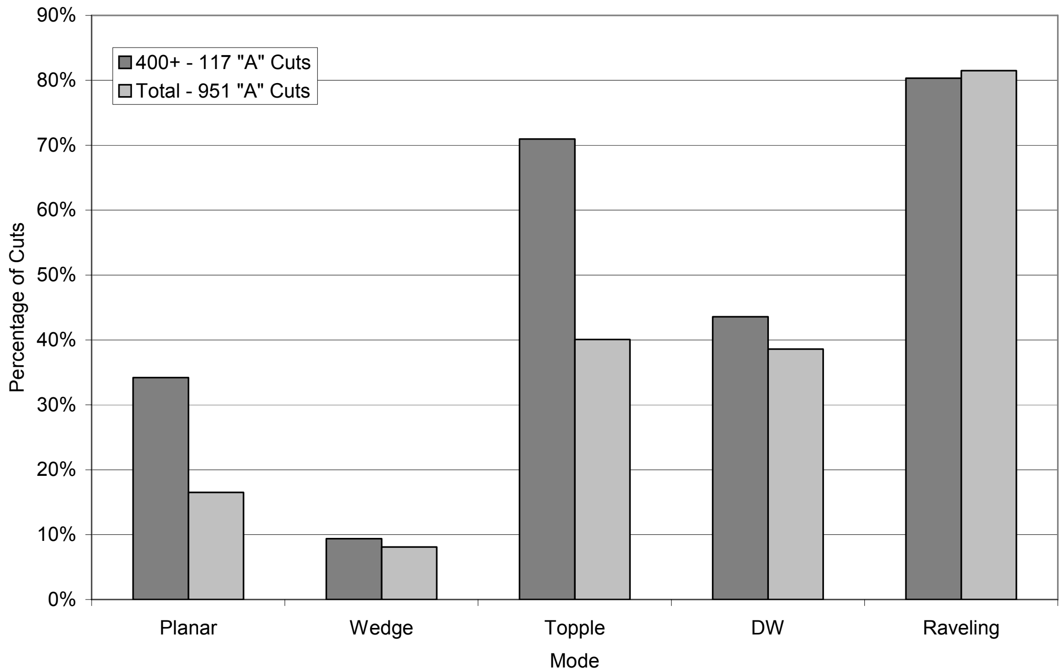

Figure 2-26: Rockfall Mode Occurrence among Cuts Scoring 400 and Above, Compared to the Total Population of Cuts

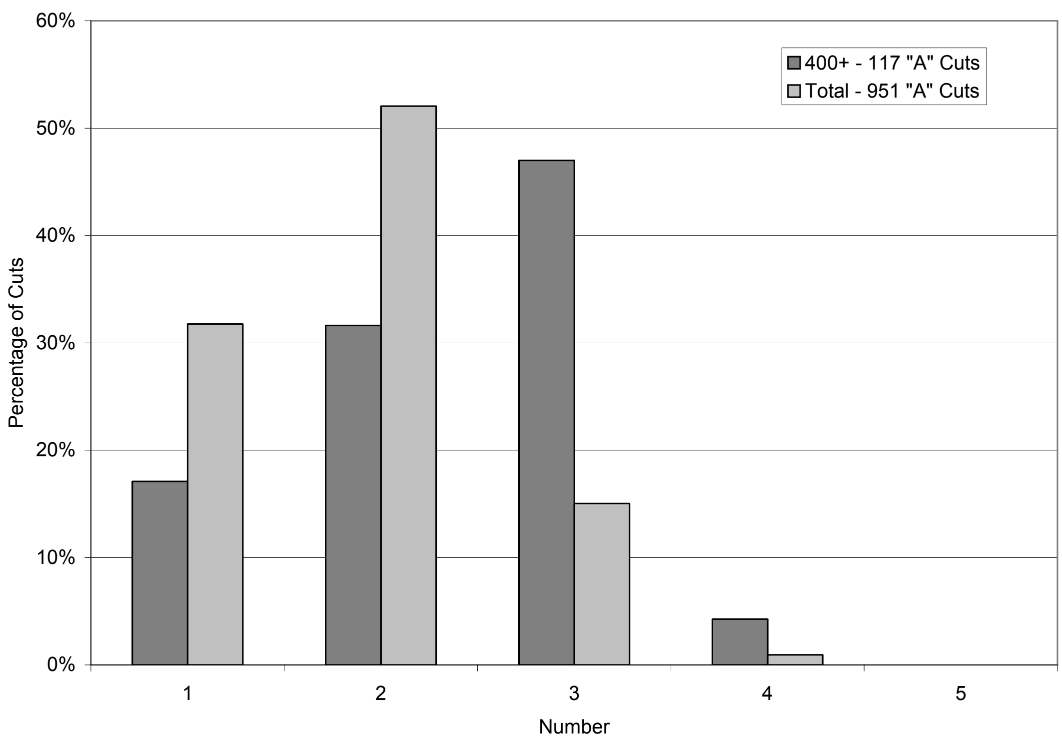

Figure 2-27: Number of Rockfall Modes among Cuts Scoring 400 and Above, Compared to the Total Population of Cuts.

On a regional basis, the cuts scoring 400 or more points tend to receive maximum points for ditch width and decision site distance regardless of region, while Region III/IV tends to have a higher percentage receiving maximum score in AVR (Figure 2-28). This is likely due to the higher traffic counts in Davison County. Similar to the data for all "A" cuts (Figure 2-26), raveling tends to appear in about 80% of the high scoring cuts regardless of region (Figure 2-29). However, 100% of the high scoring cuts in Region III/IV exhibited differential weathering, and there was no record of structural modes (planar, wedge, or topple) in Region III/IV. The topple mode was more prevalent in the high scoring cuts of Region II than in Region I.

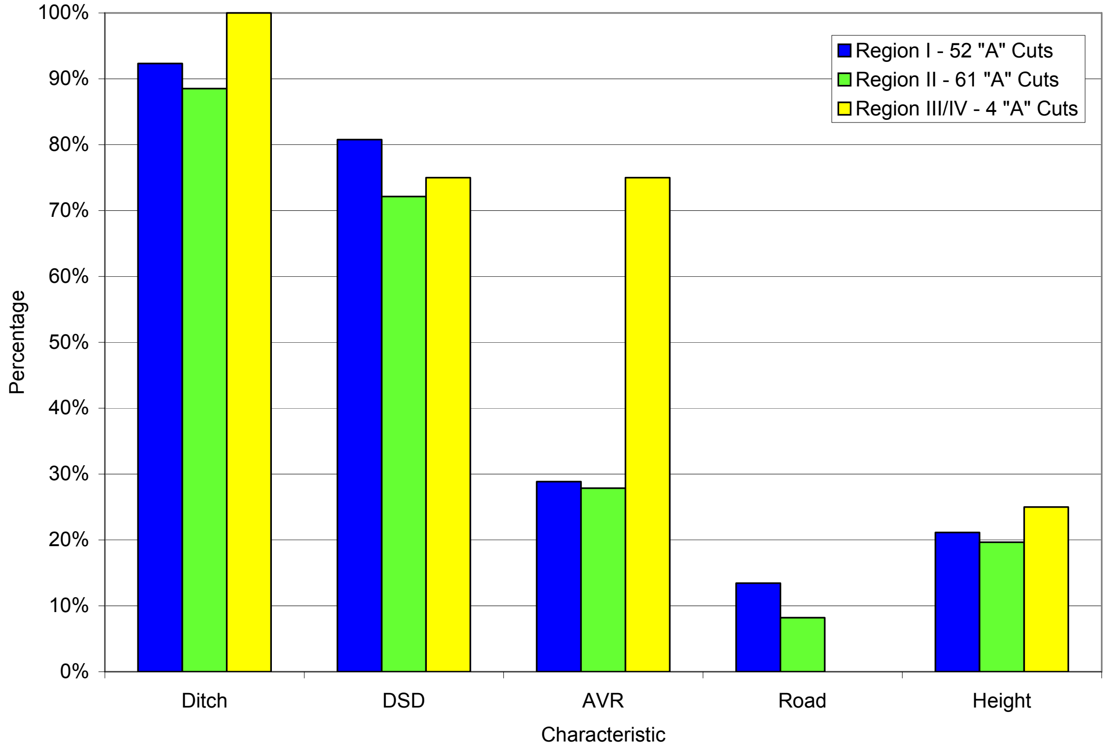

Figure 2-28: Site & Roadway Geometry Categories Receiving Maximum Score among Cuts Scoring 400 and Above on a Regional Basis

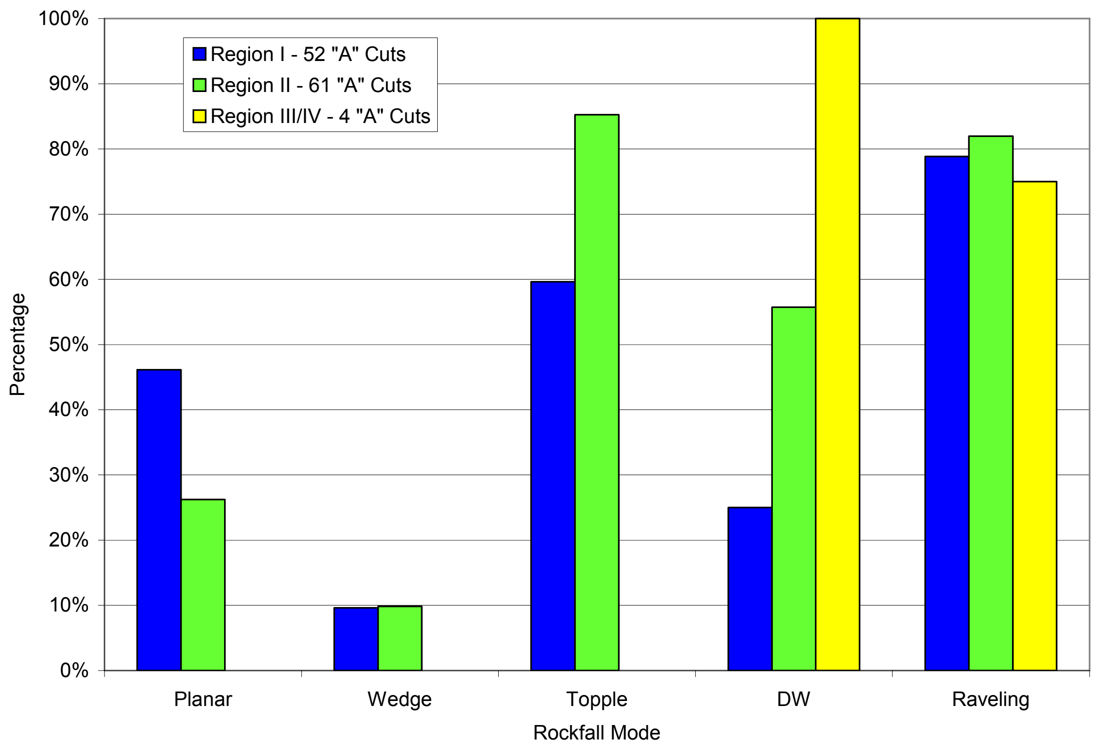

Figure 2-29: Rockfall Mode Distribution among cuts Scoring 400 and Above by Region

Chapter 3 – Summary

During the Phase I and II fieldwork for the Rockfall Management System for Tennessee, 963 "A" rated cuts were identified and 951 were scored in seventy-eight counties across the four TDOT regions, using the Tennessee Rockfall Hazard Rating System (TRHRS) developed during Phase I. Over eighty percent of the A-rated cuts are located in TDOT Regions I and II. The top twelve percent (117) have scores of 400 or greater in a scoring system with a maximum of 850. Of these 117 high scoring cuts, 113 are located in Regions I and II. The highest scoring rockcut is located along State Route 40 in Polk County in Region II with a score of 771.

Although the maximum potential score contributions for Site and Roadway Geometry and Geologic Character are similar at 443 and 400 respectively, for the average TRHRS score of 308, Site and Roadway Geometry contributes 60% of the score (192) and Geologic Character contributes 40% (116). However, for the highest rated cuts (scores 400 and above), Geologic Character contributes 48% of the score, implying that high-scoring cuts necessitate significant score contributions from both Site and Roadway Geometry and Geologic Character.

The major Site and Roadway Geometry score contributors for the entire population of "A" rated rockcuts are ditch effectiveness and decision sight distance, while high Geologic Character sub-scores are commonly the result of two rockfall modes, typically raveling and toppling. Considering only rockcuts with scores of 400 and above, decision sight distance, average vehicular risk, and slope height become greater score contributors, while Geologic Character is commonly the result of three rockfall modes, typically raveling, toppling, and planar. Consequently, structural rockfall modes are more prevalent for the highest scoring rockcuts in Tennessee.

Regionally, Region II has a relatively greater number of high-scoring rockcuts than the other regions because it contains the Ocoee River Gorge in Polk County, the Monteagle Mountain section of I-24 in Grundy and Marion Counties, the marked relief in Hamilton County, and a few high relief areas in Bledsoe, DeKalb, and Jackson Counties.

Correspondingly, Region II has relatively higher Geologic Character scores than Regions I and III, whereas, Region III has smaller Site and Roadway Geometry scores than Regions I and II because the roads are generally straighter.

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Rockfall Management System for Tennessee

Appendices

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Appendix A – Tennessee Rockfall Hazard Rating System (RHRS)
Appendix B – Field Data Collection Sheet (paper form)
Appendix C – PDA (Personal Digital Assistant) User Manual
Appendix D – Field Training Manual
Appendix E – User Manual (help file) for the Rockfall Database (Access)
Appendix F – GIS Implementation and User Manual
Appendix G – Work Load Summary for Field Data Collection
Appendix H – Electronic Data Collection
Appendix I – Database Implementation
Appendix J – List of Publications
Appendix K – Pendragon Computer files
Appendix L – Field photograph Library Structure

Rockfall Management System for Tennessee

Appendix A:

Tennessee Rockfall Hazard Rating System

December 2007

TDOT

I. Introduction

The Tennessee Rockfall Hazard Rating System (RHRS) is a tool used to identify roadcuts that are potentially hazardous due to rockfall risk, and is part of Tennessee's Rockfall Management System (Bateman, 2001). This Appendix describes the process for selecting potentially hazardous roadcuts (Sections II and III), and the basis for scoring each of the characteristics at a potentially hazardous roadcut with the Tennessee RHRS (Section IV). The scoring for certain characteristics (ditch effectiveness, geologic characteristics, presence of water on cut, and rockfall history) in the Tennessee RHRS is modified from the National Highway Institute (NHI) RHRS (1993) . The basis for these changes is described along with the new scoring approaches in Section IV.

II. Tennessee's RHRS Method: Slope Identification

As used here, a hazardous roadcut is a roadcut or rock slope that has potential for rockfall events to reach the roadway. The process of identifying potentially hazardous roadcuts on Tennessee state roads begins with a virtual drive-through, using TRIMS - the Tennessee Roadway Information Management System. TRIMS is an integrated roadway management tool that incorporates video-logging of all state routes with photographs captured at one-hundredth-of-a-mile increments (Figure 1). Potentially hazardous roadcuts are identified during the virtual drive-through, and the corresponding log miles are recorded. Other roadway information for each roadcut, such as average daily traffic and speed limit, is recorded and used if the roadcut subsequently is given a detailed rating.

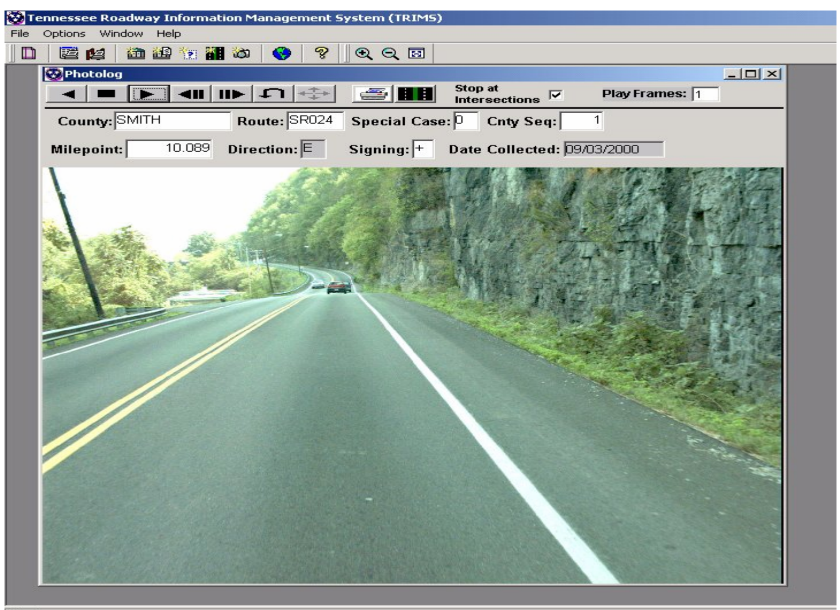

Figure 1 Example TRIMS user screen

III. Tennessee RHRS Method: Preliminary Ratings

After identifying potentially hazardous cuts using TRIMS, the roadcuts are visited, evaluated and assigned preliminary ratings according to the following NHI guidelines (NHI, 1993).

A – Slopes have a moderate-to-high potential for rocks to reach roadway and/or high historical rockfall activity.

B – Slopes have a low-to-moderate potential for rocks to reach roadway and/or moderate historical rockfall activity.

C – Slopes have a negligible-to-low potential for rocks to reach roadway and/or low historical rockfall activity.

When evaluating the potential for rocks to reach the roadway, the following are considered:

1. Impact marks on the road.
2. Ditch effectiveness, including width and shape of catchment
3. Estimated size and amount of material per event.
4. Presence of launching features.

A motorist’s decision site distance should be considered if the potential for rocks to reach the roadway is moderate. A limited decision site distance with moderate potential for rocks to reach the roadway is considered hazardous, and the roadcut should be assigned a preliminary rating of A.

When evaluating the historical rockfall activity, the following are considered:

1. Frequency and presence of rockfall on roadway.
2. Frequency of removal of rock debris from catchment/roadway.
3. Amount of material in the catchment (particularly in the absence of maintenance reports)
4. Number of impact marks in the road (particularly in the absence of maintenance reports)

IV. Tennessee RHRS Method: Detailed Rating System.

The purpose of the detailed rating system is to numerically differentiate the potential risk at identified roadcuts (NHI, 1993). As a result, roadcuts can be sorted and prioritized for maintenance/remediation based on their scores. Only roadcuts with a preliminary rating of *A* receive the detailed rating. The primary method of data collection for the Tennessee RHRS detailed ratings uses personal digital assistants (PDA's) (Bellamy, 2002) with paper forms as back–up.

Most categories and scoring techniques for the Tennessee RHRS detailed ratings are the same as with the NHI (1993) RHRS. However, three categories were modified to provide better characterization of critical features along Tennessean roadcuts, and to improve repeatability and consistency among raters. Consequently, the detailed rating system has the following categories:

- Slope height
- Ditch effectiveness
- Average Vehicle Risk (AVR)
- Roadway width
- Percent of Decision Site Distance (%DSD)
- Geologic characteristics
- Presence of water on slope
- Rockfall history

Like the NHI RHRS, each factor in the Tennessee detailed rating is assigned a score that increases exponentially with degree of hazard, and the scores of all categories are summed to yield an overall score. The exponential scoring of each category benchmark, from 3 to 81 points, is calculated on the basis of 3^x where $x = 1$ (low risk) to 4 (high risk). However, some categories allow use equations for determining scores within the continuum of 1 to 100 points. Additionally, when categories in the Tennessee detailed rating are modified from the NHI version, their scoring methods are weighted to maintain consistency with the NHI RHRS. The detailed description of each category in the Tennessee RHRS Detailed Rating is described below.

1. Slope Height.

The Tennessee RHRS allows slope height to be determined in two ways: by visually estimating or by measuring. Raters may find that, through experience, their ability to visually estimate the height of a roadcut produces reliable results comparable to measured values, and therefore prefer estimation as the method to determine slope height. Estimation of height should be done to the nearest ten feet, and until the rater is comfortable with the reliability of his/her estimation, it should be done in conjunction with measurement so that the two results can be compared.

Measurement. The height of a roadcut is determined using the following steps, according to NHI-recommended methods (NHI, 1993):

a) Measure angles in the vertical plane from near and far shoulders (edges of pavement) to top of roadcut (see Figure 2), using a clinometer.
b) Measure width of roadway between shoulders using a measuring wheel
c) Calculate height of roadcut using the following equation (NHI, 1993):

$$\text{Total Slope Height} = \frac{(X) * \sin\alpha * \sin\beta}{\sin(\alpha - \beta)} + H.I.$$

Where: X = Horizontal distance between α between β

α = Angle measured from near shoulder

β = Angle measured from far shoulder

$H.I.$ = height of clinometer above pavement

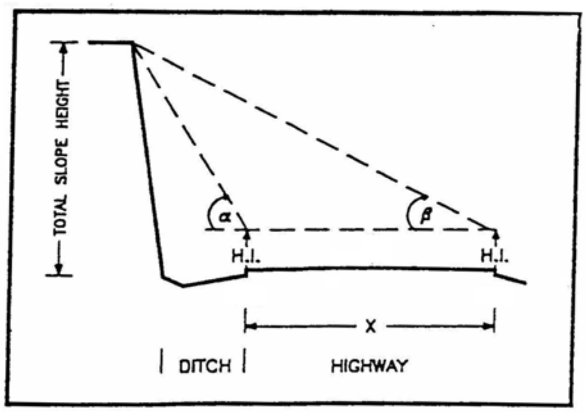

FIGURE 2. Diagram showing where slope height observations are made at a roadcut (modified from NHI, 1993).

Scoring. Following NHI guidelines, the score is calculated with the following equation

$$3^x \text{ where } x = \frac{\textit{Slope Height}(ft)}{25}, \text{ or}$$

by using the scoring table (Table 1).

Table 1. *Slope Height* scoring table (NHI, 1993).

Slope Height Scoring Table							
Height (ft)	**Score**		**Height (ft)**	**Score**		**Height (ft)**	**Score**
9	1		**68**	20		**87**	46
10 - 20	2		**69**	21		**88**	48
21-28	3		**70**	22		**89**	50
29-34	4		**71**	23		**90**	52
35-38	5		**72**	24		**91**	55
39-42	6		**73**	25		**92**	57
43-45	7		**74**	26		**93-94**	60
46-48	8		**75**	27		**95**	62
49-51	9		**76**	28		**96**	65
52-53	10		**77**	29		**97**	71
54-55	11		**78**	31		**98**	74
56-57	12		**79**	32		**99**	78
58-59	13		**80**	34		**100**	81
60	14		**81**	35		**101**	85
61-62	15		**82**	37		**102**	88
63	16		**83**	38		**103**	92
64-65	17		**84**	40		**104**	97
66	18		**85**	42		**105**	100
67	19		**86**	44			

2. Ditch Effectiveness.

The NHI (1993) Ditch Effectiveness category is a subjective evaluation of site conditions that prevent rock from reaching the roadway. In the Tennessee RHRS, this category was modified to increase objectivity by evaluating ditch effectiveness as a function of the TDOT recommended design catchment-width, the slope of catchment area, and the presence of launching features.

Measurement.

a) Measure actual catchment width, and record value for comparison with the TDOT design width.

b) Determine whether catchment slope has a 6:1 or greater width to depth ratio and record as “yes” or “no”.

c) Any catchment with 6:1 or greater ratio is considered less hazardous, while a ratio less than 6:1, including a flat catchment, is considered more hazardous.

Note the presence of any launching features that could allow a falling rock to bypass the catchment.

Scoring.

a) Obtain the recommended design catchment width for a new road cut with the measured slope height using the TDOT Design Catchment Width Table (Table 2.), which is based on rockfall simulations using Colorado's Rockfall Simulation Program 4.0 (CRSP). The design widths are presented for both vertical and inclined slopes for a particular height of a new roadcut.

b) Evaluate actual catchment width as a percentage of the recommended catchment width for a new road cut. Then, using the Ditch Effectiveness Criteria Scoring Table (Table 3.), identify the correct column for the calculated percentage and select the appropriate row on the basis of catchment slope and launching features.

TABLE 2. TDOT recommended design catchment width for new slopes.

Design Catchment Width (feet)		
Slope Height (feet)	Recommended Catchment Width, Vertical Slope (feet)	Recommended Catchment Width, Inclined Slope (feet)
0-40	18	18
40-50	18	24
50-60	24	30
60-70	28	34
70-80	32	38
80-100	36	42
100-125	36	42
125-175	40	48
>175	52	60

TABLE 3. *Ditch Effectiveness* scoring table.

Ditch Effectiveness Criteria				
Percent of Design Catchment Width from Table	>90%	70% - 90%	50% - 70%	<50%
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment Slope **OR** Launch Features	9	27	81	81
Score w/ Poor Catchment Slope **AND** Launch Features	27	81	81	81

3. Average Vehicle Risk (AVR)

Measurement.
The average vehicle risk (AVR) is determined by using the average daily traffic (ADT) data from TRIMS, the measured slope length, and posted speed limit (NHI, 1993):

$$AVR = \frac{ADT\,(cars/day) * SlopeLength\,(miles)}{24\,(hours/day) * Posted\ Speed\ Limit\,(mph)} \times 100\%$$

Scoring.
The score is determined by the following formula:

$$3^x, \text{ where } x = \frac{\%\,Time}{25}, \text{ or}$$

comparing the calculated AVR to values in Table 4.

TABLE 4. *Average Vehicle Risk* scoring table (NHI, 1993).

Average Vehicle Risk Scoring Table							
AVR %	**Score**		**AVR %**	**Score**		**AVR %**	**Score**
9	1		**68**	20		**87**	46
10 - 20	2		**69**	21		**88**	48
21-28	3		**70**	22		**89**	50
29-34	4		**71**	23		**90**	52
35-38	5		**72**	24		**91**	55
39-42	6		**73**	25		**92**	57
43-45	7		**74**	26		**93-94**	60

Average Vehicle Risk Scoring Table							
AVR %	**Score**		**AVR %**	**Score**		**AVR %**	**Score**
46-48	8		**75**	27		**95**	62
49-51	9		**76**	28		**96**	65
52-53	10		**77**	29		**97**	71
54-55	11		**78**	31		**98**	74
56-57	12		**79**	32		**99**	78
58-59	13		**80**	34		**100**	81
60	14		**81**	35		**101**	85
61-62	15		**82**	37		**102**	88
63	16		**83**	38		**103**	92
64-65	17		**84**	40		**104**	97
66	18		**85**	42		**105**	100
67	19		**86**	44		-	-

4. Roadway Width

Measurement.

The roadway width is measured from edge of pavement to edge of pavement perpendicular to the longitudinal axis of the road. If the width varies along a roadcut, it is measured at the narrowest width.

Scoring.

The score is obtained from the following formula:

$$3^x, \text{ where } x = \frac{52 - Roadway\ Width(ft.)}{8}, \text{ or}$$

by comparing measured widths to values in Table 5.

5. Percent Decision Sight Distance (DSD)

The decision sight distance (DSD) is the maximum road length that a driver has to identify and avoid a rockfall hazard.

Measurement.

The DSD is measured along the edge of pavement in the direction of oncoming traffic. It is the distance from the roadcut to where a 6” object disappears when viewing the road at a height of 3.5 ft above the ground. Where both directions of traffic are likely to be affected by rock in the road, the distance is measured in both directions and the shorter distance is recorded. The measured distance is recalculated as a percent of the recommended AASHTO (1984) distance for that speed limit. The recommended AASHTO distances are shown in Table 6.

TABLE5. *Roadway Width* scoring table (NHI, 1993).

Roadway Width Scoring Table				
Width	**Score**		**Width**	**Score**
18	100		**35**	10
19	93		**36**	9
20	81		**37**	8
21	71		**38**	7
22	62		**39**	6
23	54		**40**	5
24	47		**41**	5
25	41		**42**	4
26	36		**43**	3
27	31		**44**	3
28	27		**45**	3
29	24		**46**	2
30	21		**47**	2
31	18		**48**	2
32	16		**49**	2
33	14		**50**	1
34	12		-	-

TABLE 6. AASHTO recommended decision sight distances.

Posted Speed Limit (mph)	**Decision Sight Distance (ft)**
25	375
30	450
35	525
40	600
45	675
50	750
55	875
60	1,000
65	1,050

Scoring.
The score is determined by the following formula:

$$3^x\text{, where } x = \frac{120 - \%DSD}{20}\text{, or}$$

by comparing the measured %DSD to values in Table 7:

TABLE 7. Percent DSD scoring table (NHI, 1993)

%DSD Scoring Table							
%DSD	**Score**		**%DSD**	**Score**		**%DSD**	**Score**
36	100		**53**	40		**69-70**	16
37	96		**54**	38		**71**	15
38	90		**55**	36		**72**	14
39	86		**56**	34		**73-74**	13
40	81		**57**	32		**75**	12
41	77		**58**	30		**76-77**	11
42	73		**59**	29		**78-79**	10
43	69		**60**	27		**80-81**	9
44	65		**61**	26		**82-83**	8
45	62		**62**	24		**84-85**	7
46	58		**63**	23		**86-88**	6
47	55		**64**	22		**89-92**	5
48	52		**65**	21		**93-97**	4
49	49		**66**	19		**98-103**	3
50	47		**67**	18		**104-112**	2
51	44		**68**	17		**113**	1
52	42		-	-		-	-

6. Geologic Characteristics

The characterization of geology in the Tennessee RHRS is significantly modified from the NHI (1993) characterization. The Tennessee RHRS characterizes all potential failure modes at a roadcut, scores each failure mode, and sums the scores rather than scoring only the mode with the greatest potential for failure, as is done in the NHI RHRS. The NHI scheme distinguishes structurally controlled rockfall (Geologic Character Case 1) from weathering controlled rockfall (Geologic Character Case 2) (NHI, 1993). The Tennessee RHRS, instead, subdivides the above cases into specific failure modes. Structurally controlled failure modes are planar slide, wedge slide, and toppling failure, while the weathering controlled failure modes are differential weathering, and raveling.

Characteristics pertinent to all failure modes are the relative *abundance* of the failure zone as a percentage of the total cut surface area, and *block size*, which is the longest dimension of the blocks. Characteristics unique to planar and wedge failure are *steepness* of failure plane(s) and the micro- and macro-*friction* profiles of the failure plane(s). The a*mount of relief* is a characteristic unique to differential weathering, and block *shape* is unique to raveling.

Scores for the different failure modes are additive up to a maximum score of 300. This bounding value is used because the NHI (1993) RHRS allows a maximum score of 300 for the combination of the Case1/Case2 geology score and the Block Size score. Thus, the Tennessee RHRS has the same maximum contribution from geology to the total rockfall hazard score as compared to the original NHI RHRS despite summing the scores of the different operative failure modes. The additive scoring also does not overemphasize the geological category in the overall hazard score because for about 80 roadcuts with detailed ratings in Phase I, only one yielded a value that would have exceeded the cap of 300.

Since potential planar and wedge failures are characterized by four criteria in the Tennessee detailed system, as opposed to three criteria in the NHI system (Case1 with Block Size), the scores for the *steepness* and *friction* categories are each weighted approximately half of the 3^x value (rounded to the nearest integer) to retain the same weighting as the NHI system (Case 1 with Block Size). Similarly, scores for toppling *abundance* and *block size* are weighted approximately one-and-a-half times the 3^x value, because steepness and friction are not considered for toppling, so that total potential score matches the NHI system (Case 1 with Block Size).

For raveling, the scores for *shape* are capped at 27 points because only three options exist for block shape (tabular = 3, blocky = 9, round = 27), and using the lower three bin scores (not 81) prevents large scores that would overestimate the hazard due to raveling, particularly when it usually yields blocks less than 1 foot in linear dimension that many cars can clear without impact.

Measurement Methods and Scoring

Abundance Measurement. The relative abundance of a failure mode is determined by visual inspection and is expressed as a percentage of the total slope-face surface area, where the rock face is susceptible to the failure mode. Visual scoring aids were developed to help raters to achieve reproducibility with the assessment of abundance percentage (see Figure 3). Additionally, photo-scoring aids are also being compiled to provide representative field examples for abundances.

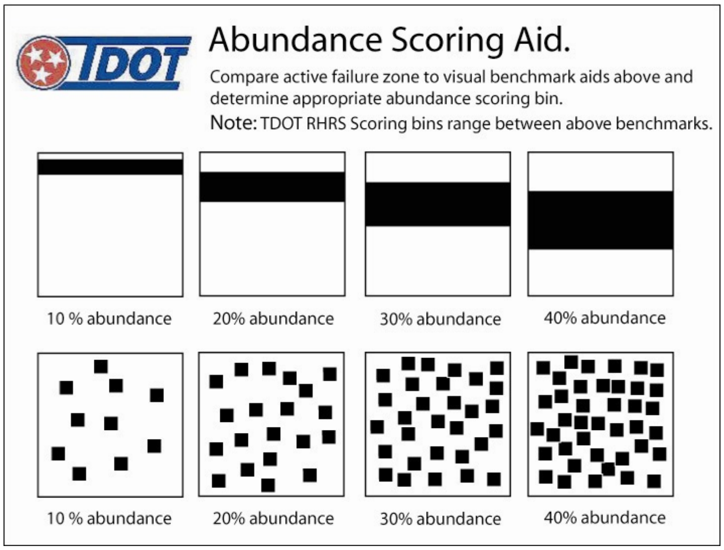

Figure 3 Visual scoring aid for a*bundance*

Abundance Scoring. The measured relative abundance of rocks susceptible to a failure mode is scored as:

Abundance	<10%	10-20%	20-30%	>30%
Score	**3**	**9**	**27**	**81**

For toppling, *abundance* is scored as:

Abundance	<10%	10-20%	20-30%	>30%
Score	**5**	**14**	**41**	**122**

Block Size Measurement. The block size of a failure mode is determined by visually inspecting rock blocks that have shed from the cut and/or have the potential to shed. Representative blocks are selected and the longest dimension measured. Given that blocks typically break apart when they fall and impact the ground, the size of in situ blocks should be given preference for measurement over the size of blocks that are already on the ground.

Block Size Scoring. The measured longest dimension of the representative block size is scored as:

Block Size	<1 ft	1 ft - 3 ft	3 ft - 6 ft	>6 ft
Score	**3**	**9**	**27**	**81**

For toppling, block size is scored as:

Block Size	<1 ft	1 ft - 3 ft	3 ft - 6 ft	>6 ft
Score	**5**	**14**	**41**	**122**

Steepness Measurement. The steepness of a failure plane or the line of intersection for a wedge failure is estimated or measured using a clinometer, and recorded in degrees from horizontal.

Steepness Scoring. The benchmark scores for steepness are:

Steepness	0 - 20º	20-40º	40-60º	>60º
Score	**2**	**5**	**14**	**41**

Friction Measurement. The micro- and macro-friction of a surface susceptible to planar failure or wedge failure is measured by visual inspection with the aid of friction profiles (Figure 4).

.

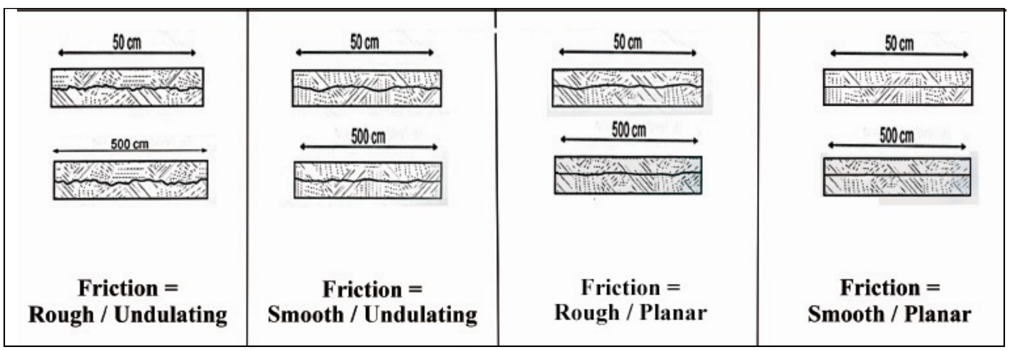

Figure 4 Visual scoring aid for *friction* showing micro- and macro- friction profiles (modified from Barton, 1973)

Evaluation of the surface(s) is made relative to the sliding direction. The macrofriction is identified as planar or undulating (non-planar), and the microfriction is identified as rough or smooth.

Friction Scoring. The benchmark scores for friction are:

Friction (micro/macro)	Rough/Undulating	Smooth/Undulating	Rough/Planar	Smooth/Planar
Score	**2**	**5**	**14**	**41**

Relief Measurement. The amount of relief created by an overhang due to differential weathering is measured at the greatest distance across the base of the overhang, perpendicular to the slope face. Where multiple overhangs occur, a representative overhang is chosen and measured. Where overhangs are inaccessible, the distance must be visually estimated.

Relief Scoring. The amount of relief of an overhang is scored as:

Relief	<1ft	1 ft - 3 ft	3 ft - 6 ft	>6 ft
Score	**3**	**9**	**27**	**81**

Shape Measurement. The shape of a block susceptible to raveling is visually identified as tabular, blocky, or round. A tabular rock has one dimension significantly shorter than the other two with a flat appearance. A blocky rock has equant dimensions predominantly and has the appearance of a cube or shoebox. A round rock lacks corners and has the potential to roll.

Shape Scoring. The shape of a block susceptible to raveling is scored as:

Shape	Tabular	Blocky	Round	-
Score	**3**	**9**	**27**	**-**

7. Presence of Water on Cut

This category is modified from the NHI (1993) category of Climate and Presence of Water on Slope. Climate was removed from the analyses because the climate in Tennessee does not vary sufficiently to warrant its use in the RHRS. Instead, the presence of water on a cut in terms of amount and type of flow on the cut is scored. It should be noted however, the flow of water on a cut can be affected by periods of heavy precipitation, recent precipitation, and prolonged drought conditions.

Measurement. Visual examination of the entire cut is necessary to identify water. If water is not present and signs of seeping water, such as concentrated areas of vegetation on the cut face are lacking, the presence of water is considered to be *none*. Areas of concentrated vegetation and/or wet rock surfaces without noticeable percolating water indicate *seeping*. Noticeably dripping or trickling water from the rock face up to an amount similar to that of a running faucet or hose is *flowing*. A large amount of water pouring from the cut is *gushing*. Figure 5 is a visual aid used to assess the presence of water on a roadcut based on the benchmark categories, with the exception of *none*.

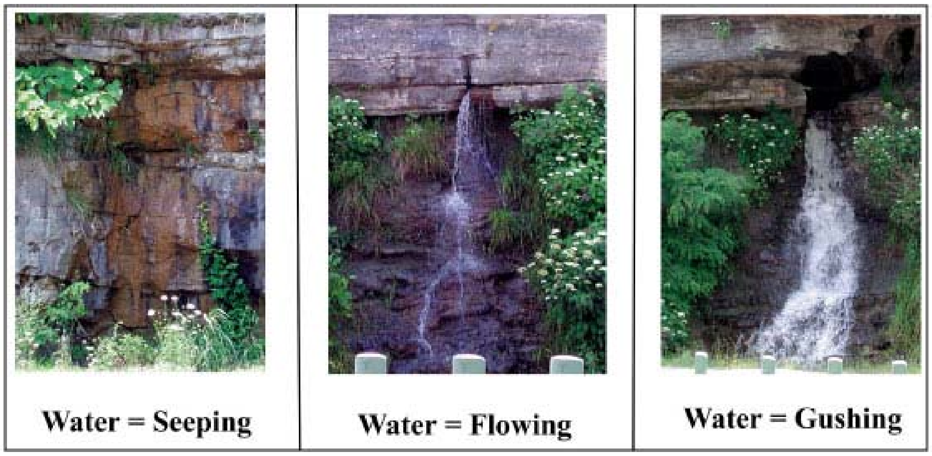

Figure 5 Visual scoring aid for *presence of water* on cut.

Presence of Water Scoring. The presence of water on cut is scored as:

Water	None	Seeping	Flowing	Gushing
Score	**3**	**9**	**27**	**81**

8. Rockfall History

This category is slightly modified from the NHI (1993) category primarily due to the limited availability of maintenance records regarding rockfall history and clean out, but the scoring benchmarks are unchanged.

Measurement and Scoring. Maintenance records are the best source of information about rockfall history. However, guidance is necessary for estimation of rockfall history if maintenance records are unavailable. When absent, rockfall history is best assessed by the amount of material in the catchment, number of impact marks in the road caused by falling rocks, and the presence of rocks in the road. The scoring is as shown in Table 8:

TABLE 8. *Rockfall History* scoring criteria.

Rockfall Benchmark	Frequency of Occurrence (From maintenance records)	Field Judgment (If no maintenance records exist)	Score
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in ditch	**3**
Several	2 per year	No impact marks in the road, no rocks in the road many rocks in the ditch	**9**
Many	3-4 per year	Few impact marks or few rocks in road	**27**
Constant	5 or more per year	Many impact marks and/or many rocks in the road	**81**

Rockfall Management System for Tennessee

Appendix B:

Field Data Collection Sheet (paper form)

December 2007

TDOT RHRS FIELD SHEET v1.0

I. TRIMS/Preliminary Data

Date ________

File No.	________		
County No.	________	Rater	________
Route No.	________	Speed Limit	________
Beg. L.M.	________	District	________
Ref C/L	________	ADT	________
County	________	Latitude	________
Region	________	Longitude	________

SCORING

1. Slope Height	________
2. AVR	________
3. % DSD	________
4. Road Width	________
5. Ditch Effectiveness	________
6. Rockfall History	________
7. Water	________
8. Geologic Character	________

TOTAL SCORE

____

II. Site and Roadway Geometry

1. Slope Height (ft)

estimated ________

alpha (a) ______ beta (b) ______

width (x) ______ ft instrument height (H.I.) ______ ft

$$\text{Slope Height} = \frac{\sin a * \sin b * X}{\sin (a - b)} + \text{H.I.}$$

2. Average Vehicle Risk (AVR)

$$\text{AVR} = \frac{\text{ADT (cars/day)} * \text{(Rock Slope Length/5280)}}{\text{((24hpd)} * \text{Speed Limit (mph))}}$$

Slope Length ________ ft Speed Limit ________ ft **AVR =** ________ %

3. % Decision Site Distance (% DSD)

Choose one: adequate, moderate, limited, very limited

3 9 27 81

OR

Calculate: ________ / ________ X 100 = ________ %

(observed DSD) / (AASHTO DSD)

4. Road Width (ft)

____

5. Ditch Effectiveness

Design Catchment Width (feet)

Slope Height (ft)	Recommended width for vertical slope	Recommended width for non-vertical slope
0 – 40	18	18
40 – 50	18	24
50 – 60	24	30
60 – 70	28	34
70 – 80	32	38
80 – 100	36	42
100 – 125	36	42
125 – 175	40	48
> 175	52	60

Effective catchment width (ft) ________ **Launching Features? (yes or no)** ________

6:1 catchment shape? (yes or no) ________

Percent of Design Catchment Width from Table	**>90%**	**70%-90%**	**50%-70%**	**<50%**
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment **OR** Launch Features	9	27	81	81
Score w/ Poor Catchment **AND** Launch Features	27	81	81	81

6. Rockfall History

Benchmark	**Frequency**	**Field Judgment**	**Score**
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in ditch	3
Several	2 per year	No impact marks in the road, no rocks in the road, many rocks in the ditch	9
Many	3 – 4 per year	Few impact marks or few rocks in the road	27
Constant	5 or more per year	Many impact marks and/or many rocks in the road	81

III. Geologic Characteristics (circle all that apply; modes are additive)

	Planar				Wedge				Topple			
Abundance	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%
score	3	9	27	81	3	9	27	81	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft
score	3	9	27	81	3	9	27	81	3	9	27	81
Steepness (degrees)	0-20	20-40	40-60	>60	0-20	20-40	40-60	>60				
score	2	5	14	41	2	5	14	41				
Friction (micro/macro)	rough/undulating	smooth/undulating	rough/planar	smooth/planar	rough/undulating	smooth/undulating	rough/planar	smooth/planar				
score	2	5	14	41	2	5	14	41				

8. Geology Score =

____

	Differential Weathering					Raveling			
Abundance	<10%	10-20%	20-30%	>30%	Abundance	<10%	10-20%	20-30%	>30%
score	3	9	27	81	score	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	Block size	<1ft	1-3ft	3- 6ft	>6ft
score	3	9	27	81	score	3	9	27	81
Relief	<1ft	1-3ft	3- 6ft	>6ft	Block Shape	tabular	blocky	round	
score	3	9	27	81	score	3	9	27	

7. Presence of Water on Slope

(choose one) none 3 seeping 9 flowing 27 gushing 81 ________

NOTES:

Version 1.0 Shows original scoring sheet as developed on the project. This was used during Phase I testing and evaluation. Version 1.1 Shows the final scoring system and sheet used on the project and was used during Phase II.

TDOT RHRS FIELD SHEET v1.1

I. TRIMS/Preliminary Data

Date ________

File No.	________		
County No.	________	Rater	________
Route No.	________	Speed Limit	________
Beg. L.M.	________	District	________
Ref C/L	________	ADT	________
County	________	Latitude	________
Region	________	Longitude	________

SCORING

1. Slope Height ________
2. AVR ________
3. % DSD ________
4. Road Width ________
5. Ditch Effectiveness ________
6. Rockfall History ________
7. Water ________
8. Geologic Character ________

TOTAL SCORE ________

II. Site and Roadway Geometry

1. Slope Height (ft)

estimated ________

alpha (a) ______ beta (b) ______

width (x) ______ ft instrument height (H.I.) ______ ft

$$\text{Slope Height} = \frac{\sin a * \sin b * X}{\sin (a - b)} + \text{H.I.}$$

2. Average Vehicle Risk (AVR)

$$\text{AVR} = \frac{\text{ADT (cars/day)} * \text{(Rock Slope Length/5280)}}{\text{((24hpd)} * \text{Speed Limit (mph))}}$$

Slope Length ________ ft Speed Limit ________ ft **AVR =** ________ %

3. % Decision Site Distance (% DSD)

Choose one: adequate, moderate, limited, very limited
3 9 27 81

OR

Calculate: ________ / ________ X 100 = ________ %
(observed DSD) / (AASHTO DSD)

4. Road Width (ft)

____

5. Ditch Effectiveness

Design Catchment Width (feet)

Slope Height (ft)	Recommended width for vertical slope	Recommended width for non-vertical slope
0 – 40	18	18
40 – 50	18	24
50 – 60	24	30
60 – 70	28	34
70 – 80	32	38
80 – 100	36	42
100 – 125	36	42
125 – 175	40	48
> 175	52	60

Effective catchment width (ft) ________ **Launching Features? (yes or no)** ______
6:1 catchment shape? (yes or no) ______

Percent of Design Catchment Width from Table	**>90%**	**70%-90%**	**50%-70%**	**<50%**
Score with 6:1 or greater catchment slope	3	9	27	81
Score w/ Poor Catchment **OR** Launch Features	9	27	81	81
Score w/ Poor Catchment **AND** Launch Features	27	81	81	81

6. Rockfall History

Benchmark	**Frequency**	**Field Judgment**	**Score**
Few	1 or less per year	No impact marks in the road, no rocks in the road, few rocks in ditch	3
Several	2 per year	No impact marks in the road, no rocks in the road, many rocks in the ditch	9
Many	3 – 4 per year	Few impact marks or few rocks in the road	27
Constant	5 or more per year	Many impact marks and/or many rocks in the road	81

III. Geologic Characteristics (circle all that apply; modes are additive)

	Planar				Wedge			
Abundance	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%
score	3	9	27	81	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft
score	3	9	27	81	3	9	27	81
Steepness (degrees)	0-20	20-40	40-60	>60	0-20	20-40	40-60	>60
score	2	5	14	41	2	5	14	41
Friction (micro/macro)	rough/undulating	smooth/undulating	rough/planar	smooth/planar	rough/undulating	smooth/undulating	rough/planar	smooth/planar
score	2	5	14	41	2	5	14	41

	Topple/B. Release				Differential Weathering			
Abundance	<10%	10-20%	20-30%	>30%	<10%	10-20%	20-30%	>30%
score	5	14	41	122	3	9	27	81
Block size	<1ft	1-3ft	3- 6ft	>6ft	<1ft	1-3ft	3- 6ft	>6ft
score	5	14	41	122	3	9	27	81
Relief					<1ft	1-3ft	3- 6ft	>6ft
score					3	9	27	81

	Raveling			
Abundance	<10%	10-20%	20-30%	>30%
score	3	9	27	81
Block size	<1ft	1-2ft	2- 3ft	>3ft
score	3	9	27	81
Block Shape	tabular	blocky	round	
score	3	9	27	

8. Geology Score =

____

7. Presence of Water on Slope

(choose one) none, seeping, flowing, gushing
3 9 27 81 ________

NOTES:

Rockfall Management System for Tennessee

Appendix C:

PDA (Personal Digital Assistant) User Manual

December 2007

Tennessee Department of Transportation

Rockfall Hazard Management System
Field PDA User Guide

Pendragon v.4.0 Field Data Rating Form

Prepared by: Matthew Mauldon[1], Marcus Kim[1] and Brett Rose[1]

Project Investigators: Vanessa Bateman[2], Eric Drumm[3], William Dunne[4], Matthew Mauldon[1]

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September, 2005

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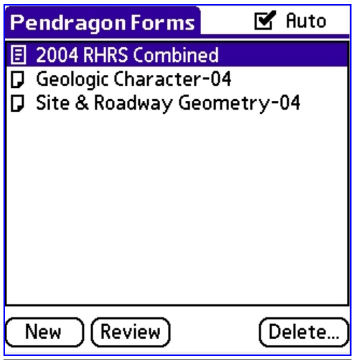
1. Preliminary Field Data Entry



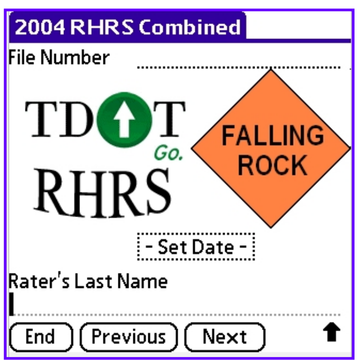
Main Menu Screen
This is the main menu screen of the PDA field data entry form.

To begin field data entry:

- Select *2004 RHRS Combined* from the menu
- Tap New button to begin data entry

Review button permits edits to be performed on previously entered data. Delete... button accesses a menu to delete a form or pervious data entry.

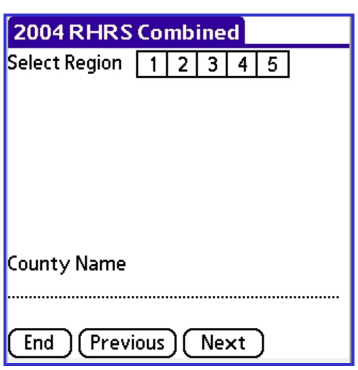
Geologic Characteristics and *Site & Roadway Geometry* can be separately accessed for reviewing and editing.



Rating Information

- Tap - Set Date - to bring up a calendar
- Select the date of the rating
- Enter your rater name using the keyboard or alphanumeric pad
- Tap Next to advance to the next screen

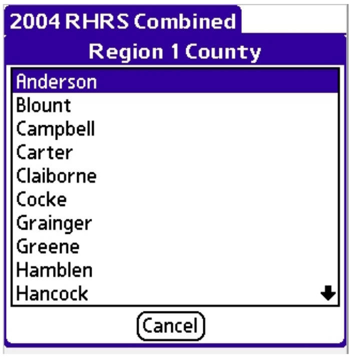
File Number is automatically assigned as more information is entered.



Region Selection
The region field stores the TDOT region number for the site.

- Select the region by tapping appropriate region number

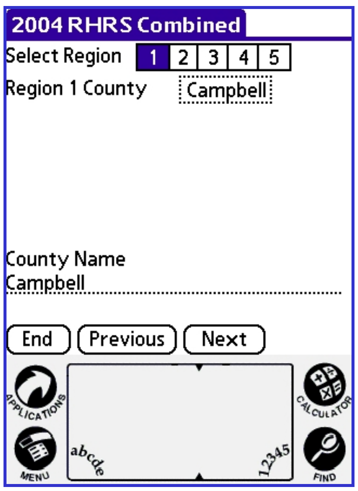
Once a region number is selected, a button to access the list of counties in the selected region appears. County name of the selected region needs to be entered before advancing to the next screen.



County Name Selection

A list of counties for the region 1 is displayed. The county field records the county where the rating was performed.

- Select the appropriate county and use the scroll arrow if needed



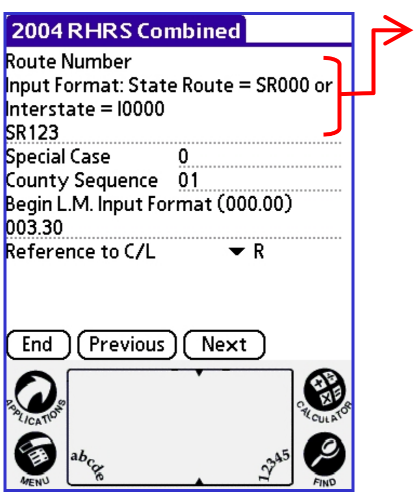
Region & County Name (Continued)

An example screen shot of completed region & county name form is shown.

Region number can be edited by simply re-selecting different number.

County name can be edited by re-selecting appropriate county number from the list.

- Tap Next to advance to the next screen



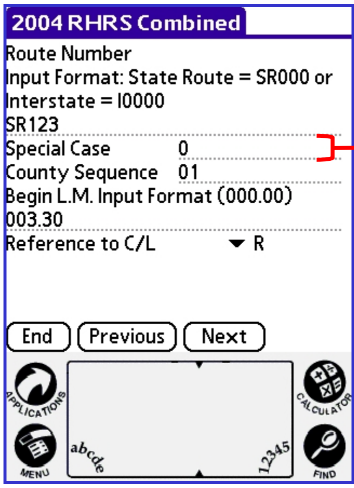
Route Number

The *Route Number* field records the state route number or in the case of the interstate, the interstate name is entered for the rating site. The route number determines the file number, and the format should be followed exactly to produce a correctly formatted file number.

E.g., State Route 70 → SR070
Interstate 81 → I0081

- Enter the appropriate route/interstate number using the keyboard or alphanumeric pad

More information needed before advancing to the next screen.



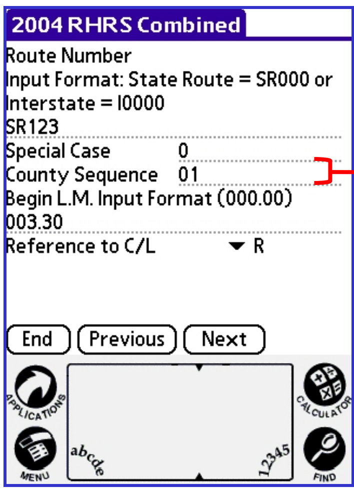
Special Case

The *special case* field indicates if the site is an interstate, off ramp, spur, etc. Numbers may be entered using the touch pad on the screen or via the standard Palm interface at the base of the screen.

None = 0 (Default)	Spur = 1	Alternate = 2
Loop = 3	By-pass = 4	Business Route = 5
Northbound = 6	Southbound = 7	Westbound = 8
Eastbound = 9		

- Enter the appropriate special case number

More information needed before advancing to the next screen

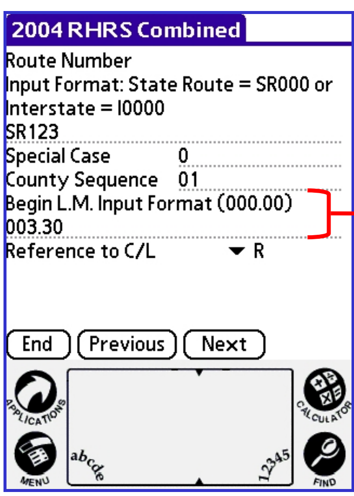


County Sequence

The *County Sequence* field indicates how many times the route occurs in the county. Each time the route enters the county the sequence number is incremented by 1 starting at 01 for the first occurrence. The log mile starts over each time the sequence number changes.

- Enter the appropriate county sequence

More information needed before advancing to the next screen.



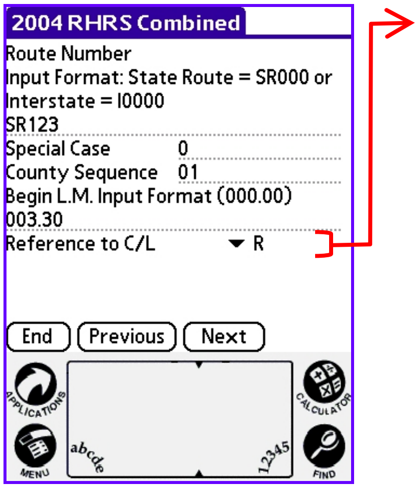
Beginning Log Mile (Begin L.M.)

The log mile for the beginning of the rating site is stated in hundredths of a mile and is called the "*Begin L.M.*" Input must consist of a six characters including the period; therefore preserve the digits to the left of the decimal point with zeros.

E.g., Log mile 3.3 → 003.30

- Enter the appropriate log mile

More information needed before advancing to the next screen.

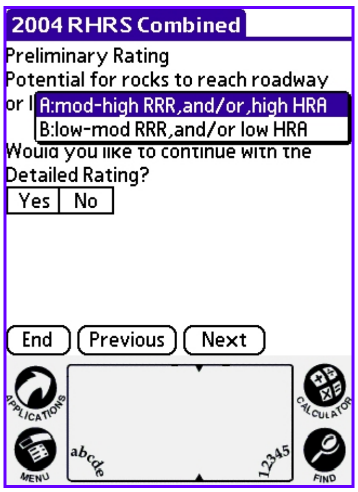


Reference to Center Line

The *Reference to C/L* field designates the side of the road where the slope is located, with respect to the centerline of the road, and **in the direction of increasing log mile**. A popup field displays L, or R, corresponding to the input formats for this field.

- Select the appropriate center line reference

Once all the required fields have been entered, the screen will automatically advance to the next screen.



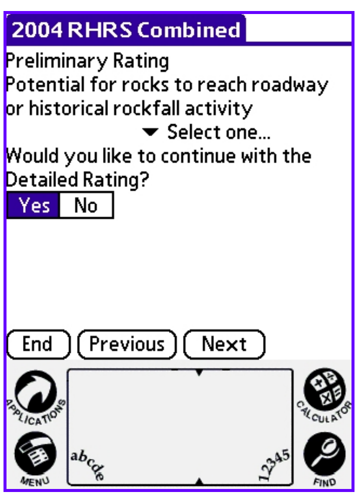
Preliminary Rating

The preliminary rating form records the rating given to the site using NHI criteria for preliminary ratings. Only A and B slopes are recorded for the TDOT RMS.

A-slope is defined as a slope with moderate to high risk of Rocks to Reach Roadway (RRR), and/or high Historical Rockfall Activity (HRA).

B-slope is defined as a slope with low to moderate risk of RRR, and/or low HRA.

- Select the appropriate preliminary slope rating from the popup field

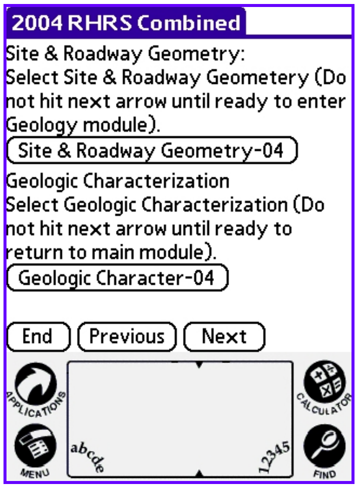


Preliminary Rating (continued)

Only A-Slopes need further detailed rating. Selecting “Yes” will automatically advance the user to the next screen, and selecting “No” will end the rating process and go back to the main menu screen.

- Select “Yes” if the rock cut is assessed to be A-slope
- Select “No” if the rock cut is assessed to be B-slope

2. DETAILED RATING: Site & Roadway Geometry

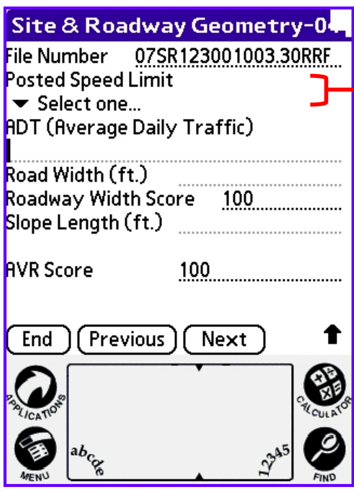


Detailed Rating Main Menu Screen

Two main categories for detailed rating are shown. *Site & Roadway Geometry* records dimensions of the site and the roadway. *Geologic Character* records information regarding geology present at the rock cut.

- Select [Site & Roadway Geometry-04]

Selecting "Site & Roadway Geometry – 04" will automatically advance the user to the next screen.

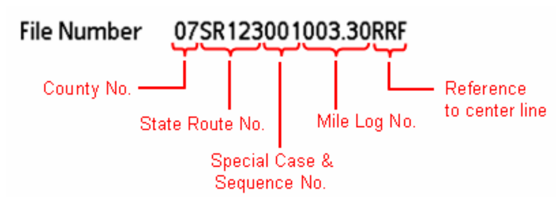


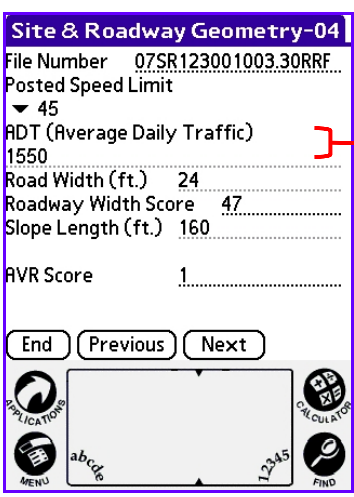
Posted Speed Limit

The posted speed limit, which maybe different from that found in TRIMS, is the speed limit at the site. The posted speed limit is one of parameters used to calculate the average vehicle risk (AVR Score).

- Tap [Select one...] to bring up a list of speed limits
- Select the appropriate speed limit from the popup field

File Number is automatically assigned using the following information.



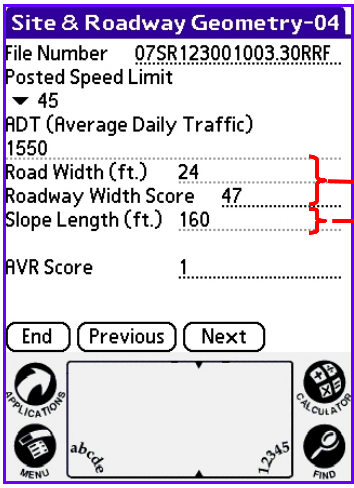


ADT (Average Daily Traffic)[1]

The ADT field corresponds to the daily traffic count, and is usually recorded prior to fieldwork for the site from TRIMS. The ADT is one of the parameters needed to calculate the average vehicle risk (AVR).

- Enter the appropriate ADT as an integer

[1]Information gather from Tennessee Roadway Information Management System (TRIM).



Road Width
The roadway width field corresponds to the measured width of the roadway from pavement edge to pavement edge. An estimate may be obtained from the TRIMS system and should be checked in the field.

- Enter the appropriate roadway width in feet

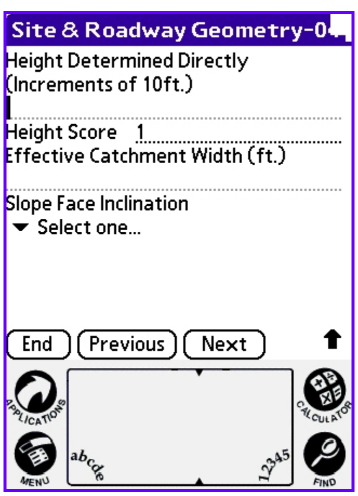
Roadway Width Score is automatically determined when the roadway width is entered.

Slope Length
The slope length field records the length of the portion of the slope that contains an A-class potential hazard to the motoring public. Slope length is one of the parameters needed to calculate the average vehicle risk (AVR).

- Enter the appropriate slope length to the nearest foot

AVR Score
The average vehicle risk score is automatically determined.

- Tap Next to advance to the next screen



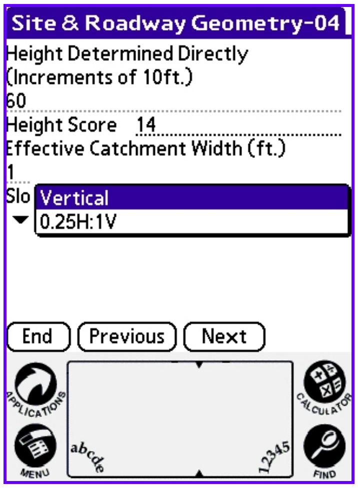
Slope Height

- Enter the height of the slope to the nearest 10 feet

Height score is automatically determined when the slope height is entered.

Effective Catchment Width
The effective catchment width extends from the slope face to the edge of the pavement with units in feet.

- Measure the catchment ditch width and record it as the effective catchment width

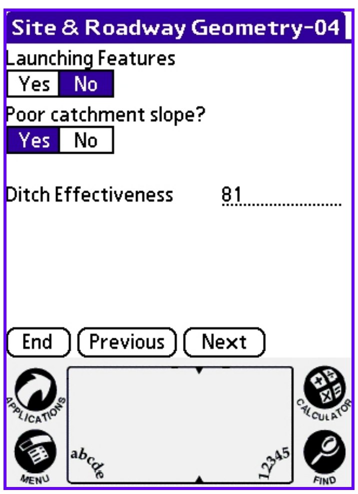


Slope Face Inclination

The facing field records whether the slope face is vertical or less than vertical. The facing is used to determine the necessary catchment width for the slope height and geometry based on TDOT's ditch criteria. This value is used to evaluate the degree of safety provided by the actual measured width.

- Tap ▾ Select one... to bring up slope face inclination list
- Select one from the list that best describes the inclination of the slope face

- Tap Next to advance to the next screen



Launching Features

The launching features field is used to record whether any benches, ramps or natural features are present that would tend to launch falling rocks into the road. If launching features are present indicate, "Yes", otherwise indicate "No".

- Select either "Yes" or "No."

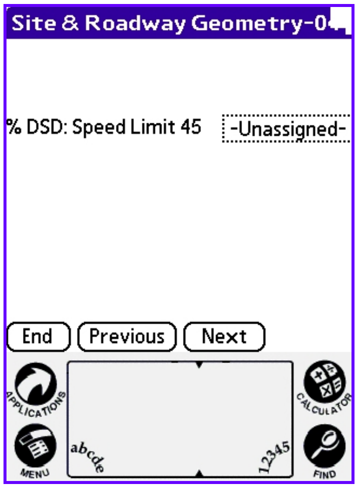
Catchment Slope Condition

If the slope of the catchment is at least 6H:1V with slope down and away from the road), then indicate "Yes", otherwise indicate "No."

- Select either "Yes" or "No"

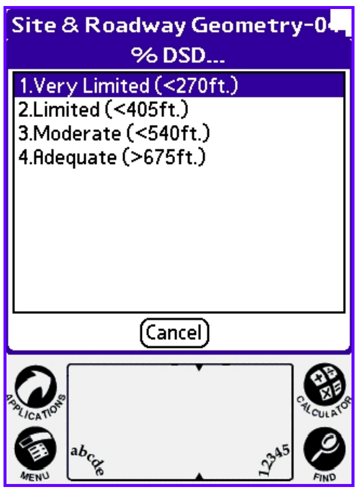
Ditch Effectiveness score is automatically determined.

- Tap Next to advance to the next screen.



% DSD (Decision Sight Distance)

- Tap -Unassigned- to bring up the list of decision sight standards



% DSD (continued)

The popup field displays the list of distances corresponding to adequate, moderate, limited, and very limited sight distance for the speed limit selected earlier. The minimum distances to meet the particular decision sight standard are in parentheses beside the standard. In this example for 45 mph, if the decision sight distance were estimated at 200ft., then the appropriate %DSD would be very limited because it's less than 270ft. On the other hand, if the sight distance were 560ft. then the %DSD would be moderate.

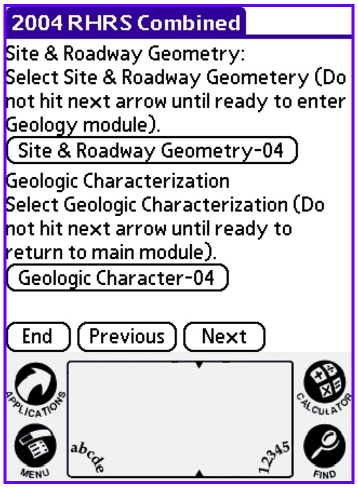
- Select the appropriate %DSD

DSD Score is automatically determined when %DSD is selected.

- Tap Next to view the Site and Roadway Geometry Composite score

- Tap Next to advance to the next screen

3. DETAILED RATING: Geologic Characteristics



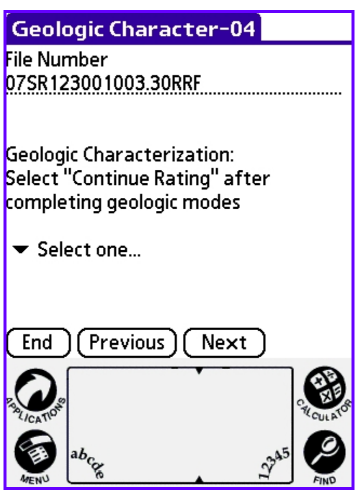
Detailed rating main menu screen

Once all required *Site & Roadway Geometry* fields are entered and the *Site & Roadway Geometry* Composite score is calculated, the screen will return to the detailed rating main menu screen.

Geologic characteristics of the rock cut need to be recorded.

- Select [Geologic Character-04]

Selecting "Geologic Character – 04" will automatically advance the user to the next screen.

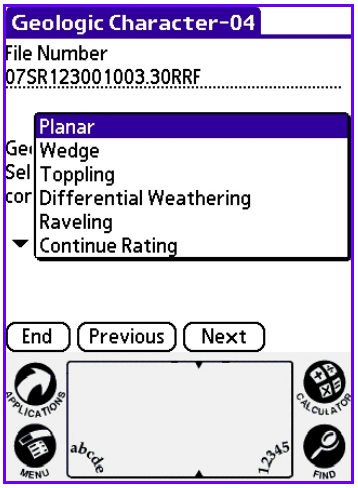


Potential Geologic Failure Modes

- Tap [▼ Select one...] to bring up the failure mode categories and to begin recording geologic information.

Ultimately, the form allows a user to select all the modes that apply to a rating site. "Continue Rating" option is available to end recording of geologic data, so as to continue on to rate water and rockfall history parameters.

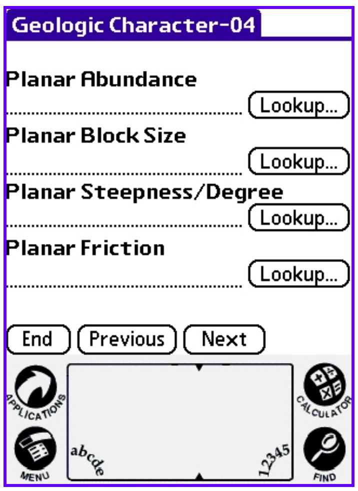
Note: The order in which data are collected does not matter.



Failure Mode Rating Example 1 – Planar

- Select Planar from the drop down menu.

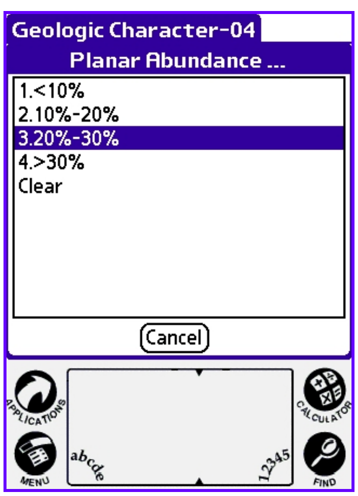
The user is automatically advanced to the next screen.



Example 1: Planar Failure Mode Rating Lookup Fields

- Select Lookup... to record data.

Selecting "Lookup…" will open up a list of scoring range pertaining to each category.



Abundance (Planar)

- Select the appropriate abundance range, using the field aids for guidance regarding the selection of an abundance category.

The Cancel button should be used to deselect the rated failure mode. For example, in the case that the Planar mode was initially rated, but not applicable, selecting Clear will score the Abundance as 0. Selection of a value flashes the planar abundance score and returns the user to the planar failure mode rating lookup screen.

Block Size (Planar)

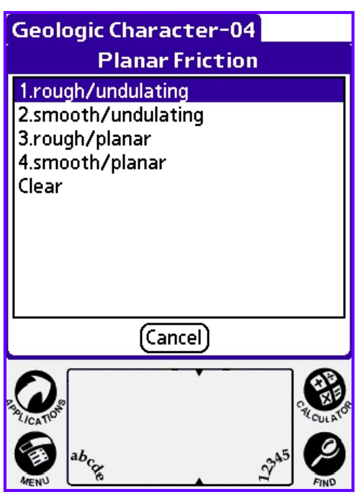
- Select the appropriate block size range.

Selection of a value flashes the planar block size score and returns the user to the planar failure mode rating lookup screen.

Steepness/Degree (Planar)

- Select the appropriate steepness/degree range for the bedding dip angle.

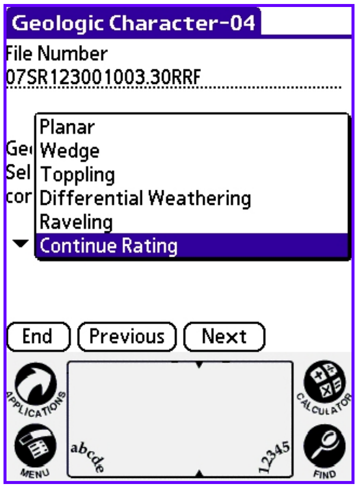
Selection of a value flashes the steepness/degree score and returns the user to the planar failure mode rating lookup screen.



Friction (Planar)

- Select the appropriate friction category, using the field aids for guidance regarding the selection of a friction category.

Selection of a value flashes the planar fiction score and returns the user to the planar failure mode rating lookup screen.

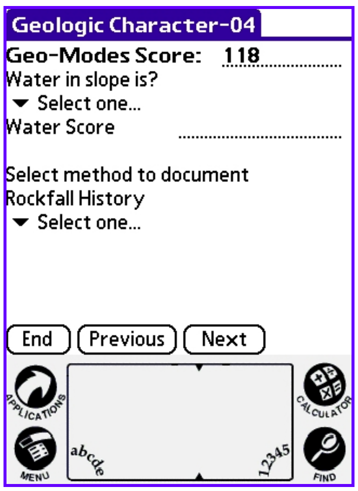


Geologic Characteristic

When all geologic characteristics that are present at the rock cut have been recorded,

- Select *Continue Rating* from the list

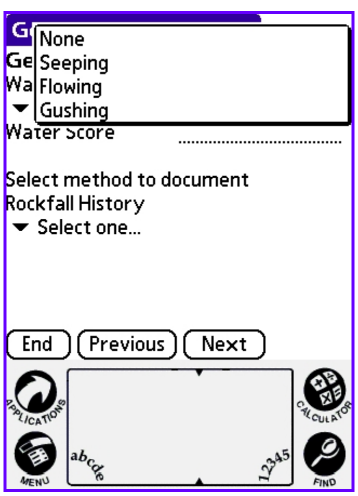
Selection of *Continue Rating* will automatically advance to the next screen.



Geologic modes composite score

The composite score of recorded potential geologic failure modes is automatically calculated and displayed.

Before proceeding to the next screen, water and rockfall history information of the rock cut need to be recorded.

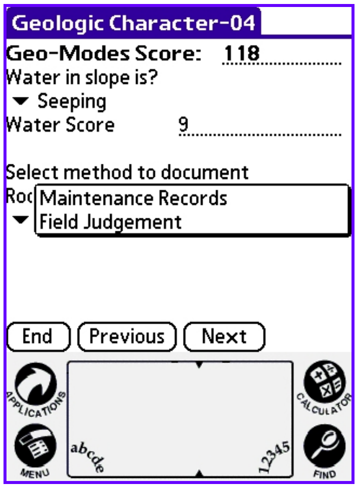


Water Score

The water field is used to record the presence of water that is on the slope at the time of rating.

- Select the appropriate presence of water category.

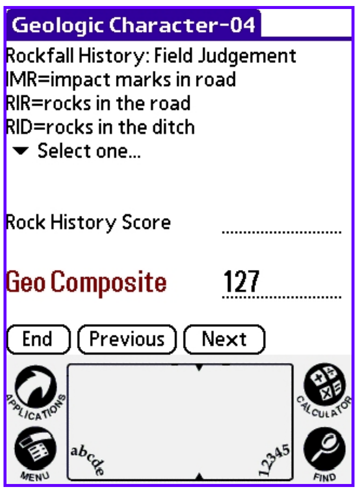
Note: The presence of water parameter is subject to change from day to day and season to season as a function of recent precipitation patterns. Use the field aid for presence of water to give guidance regarding the choice of an appropriate water category.



Rockfall History

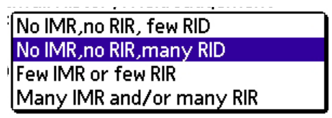
- Select the appropriate method to document the rockfall history.

Field Judgment is selected almost all the time.



Rockfall History (Field Judgment)

- Tap ▾ Select one... to bring up the list of the rockfall history field judgment categories



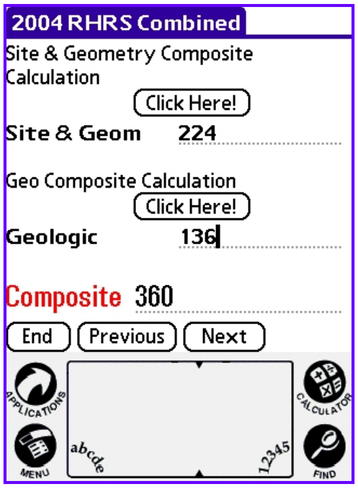
- Select the appropriate category for the Rockfall History based on the field judgment

The Rockfall History score is automatically determined based on the selected rockfall history field judgment category.

Geo Composite Score

The Geology Composite score is automatically updated.

- Tap Next to advance to the next screen



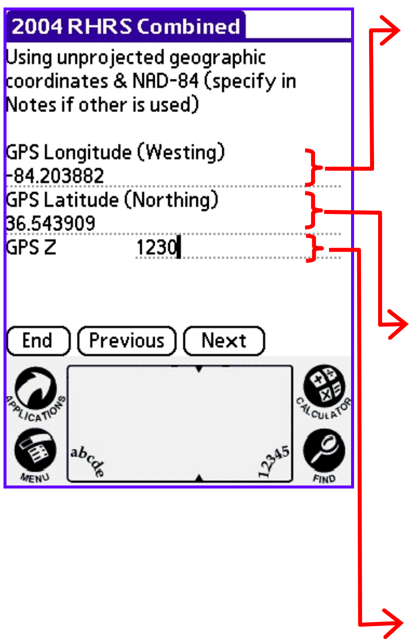
Total Composite Score

The Site & Roadway Geometry Composite score, the Geology Composite score, and the Total Composite Score are now ready to be calculated.

- Sele Click Here! to calculate composite scores of the Site & Roadway Geometry module
- Sele Click Here! to calculate composite scores of the Geologic Characteristic module

The Total Composite score is automatically calculated

- Tap Next to advance to the next screen



GPS Longitude

The *GPS Longitude* field stores the x coordinate of the spatial data.

- Enter the longitude as shown in the example

Report Longitude to hundredths of a degree.

GPS Latitude

The *GPS Latitude* field stores the y coordinate of the spatial data.

- Enter the latitude as shown in the example

Report Longitude to hundredths of a degree.

GPS Z Elevation

The GPS Z Elevation field stores the z coordinate of the spatial data.

- Enter the elevation in feet

- Tap Next to advance to the next screen

Photo Number

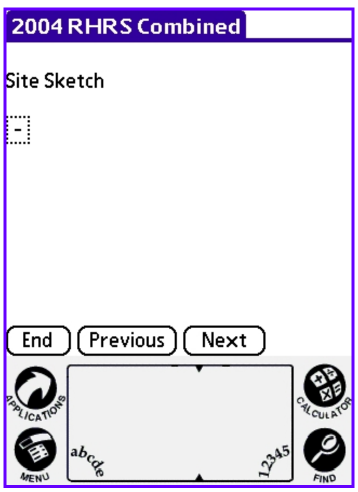
The photograph number stores the camera picture number for the rating site. The field allows the use of numbers and/or text because some camera's store picture number as alphanumeric. More than one number may be entered where more than one photograph is taken by separating the entries with commas.

- Enter photograph number using the Palm alphanumeric pad

Comments

The comments field enables a user to record brief pertinent statements about critical aspects from the site.

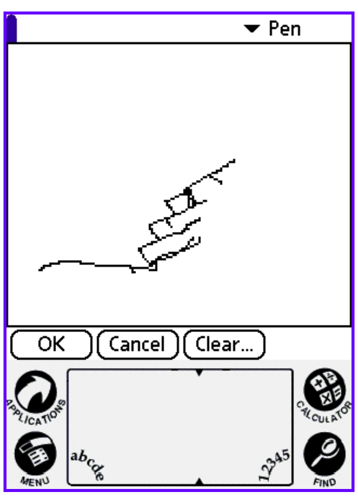
- Tap Next to advance to the next screen



Site Sketch

The Sketch option enables a user to record any critical aspects from the site in simple drawings.

- Tap [-] to open the drawing board
- Tap Next if no sketches are needed



Drawing Board

- Using the PDA pen, make a sketch of the slope
- Tap ▾ for more drawing tools option
- Select OK when finished drawing, and Cancel to exit the drawing board without saving the sketch
- Clear... clears the drawing board

Selecting either "OK" or "Cancel" from the drawing board will return the user to the Site Sketch screen

- Tap Next to advance to the next screen

TDOT Rockfall Hazard Rating System field data entry is now complete. The screen will automatically return to the main menu screen, where the user can review/edit the recently completed rating file along with other previous files.

Rockfall Management System for Tennessee

Appendix D:

Field Training Manual

December 2007

TDOT

Tennessee Department of Transportation

Rockfall Hazard Management System Training Manual

Geologic Failure Modes Identification and Abundance Assessment

October, 2005

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Project Investigators: Vanessa Bateman[2], Eric Drumm[3], William Dunne[4], Matthew Mauldon[1]

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[4]University of Tennessee, Dept. of Geological Sciences, Knoxville, TN

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Cover pictures (from top to bottom): SR70, Hawkins County, TN; SR36, Unicoi County, TN; SR133, Johnson County, TN.

Chapter 1:

Geologic Failure Mode Identification Visual Aids

The purpose of Chapter 1 is to provide representative visual aids for 5 potential geologic failure modes specified in the Tennessee Rockfall Hazard Rating System. These failure modes are (1) Planar slide, (2) Wedge slide, (3) Topple failure, (4) Differential Weathering, and (5) Raveling.

10 example pictures of road cuts are shown for each geologic failure mode mentioned above. These road cut pictures are accompanied by annotations to highlight the geologic failure mode features present at the cut. In addition, dashed lines and arrows are used to further enhance the features that are being discussed.

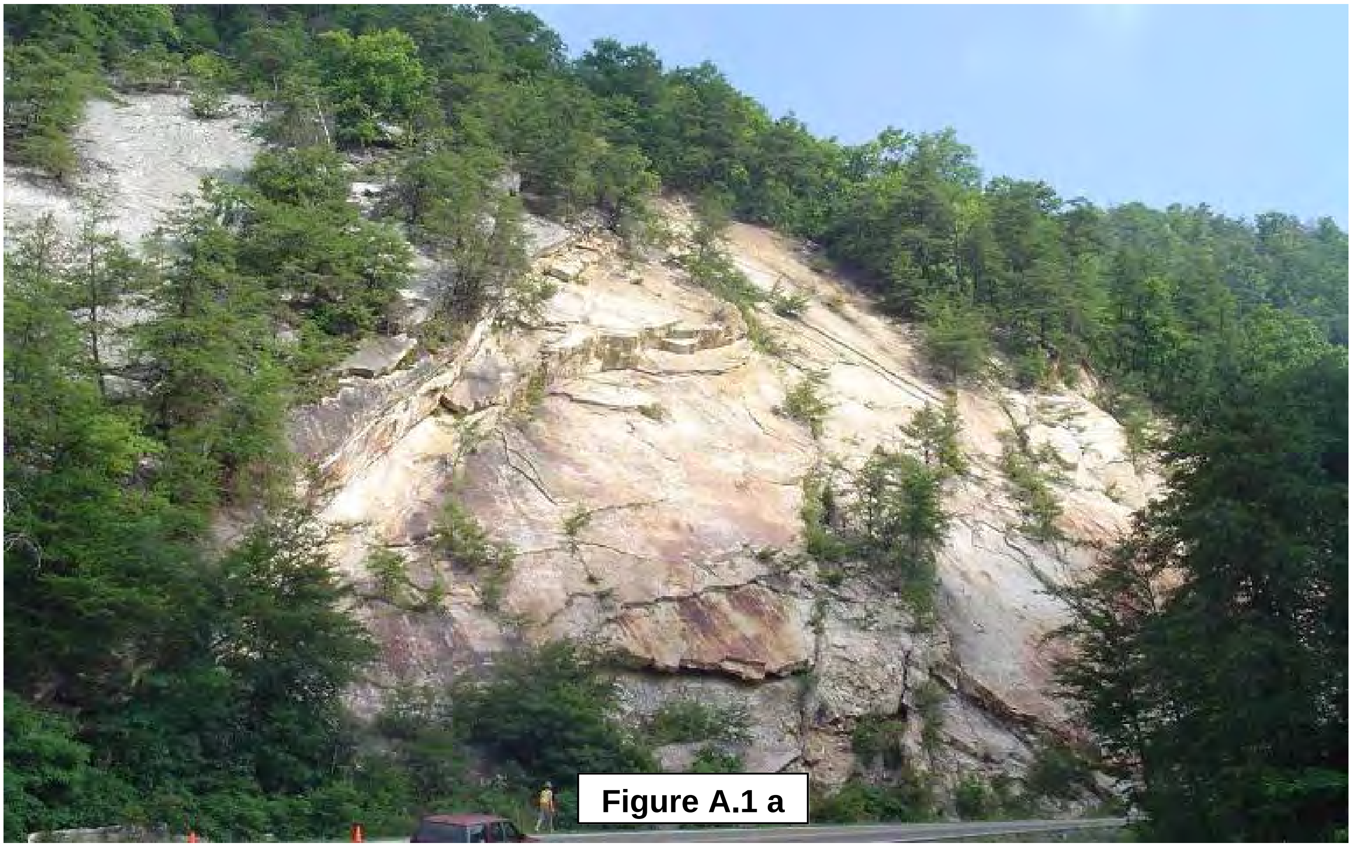
Chapter 1.1:

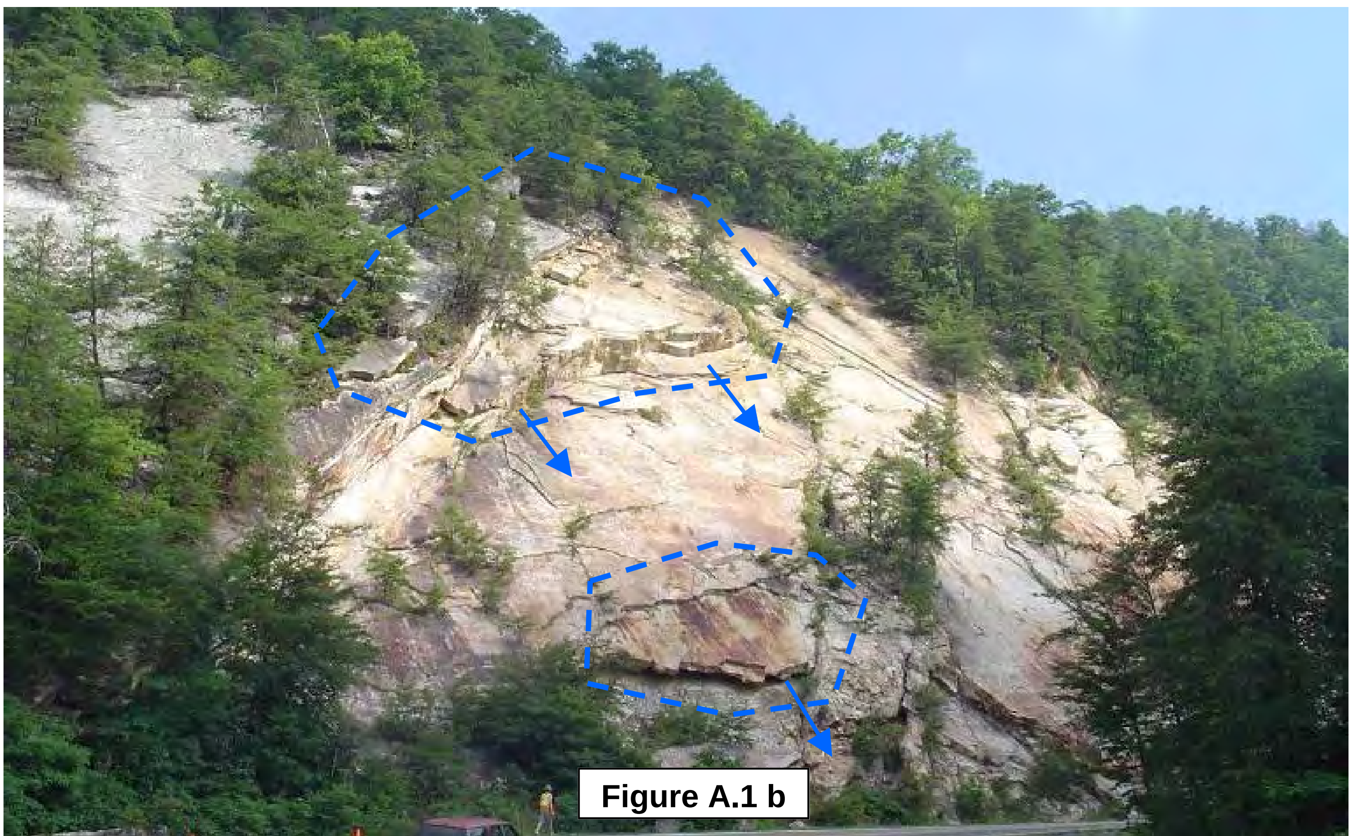
Planar Slide Failure

Planar slide failure require a planar sliding surface, typically a bedding plane or a large fracture, oriented in such a way that sliding blocks can access the roadway.

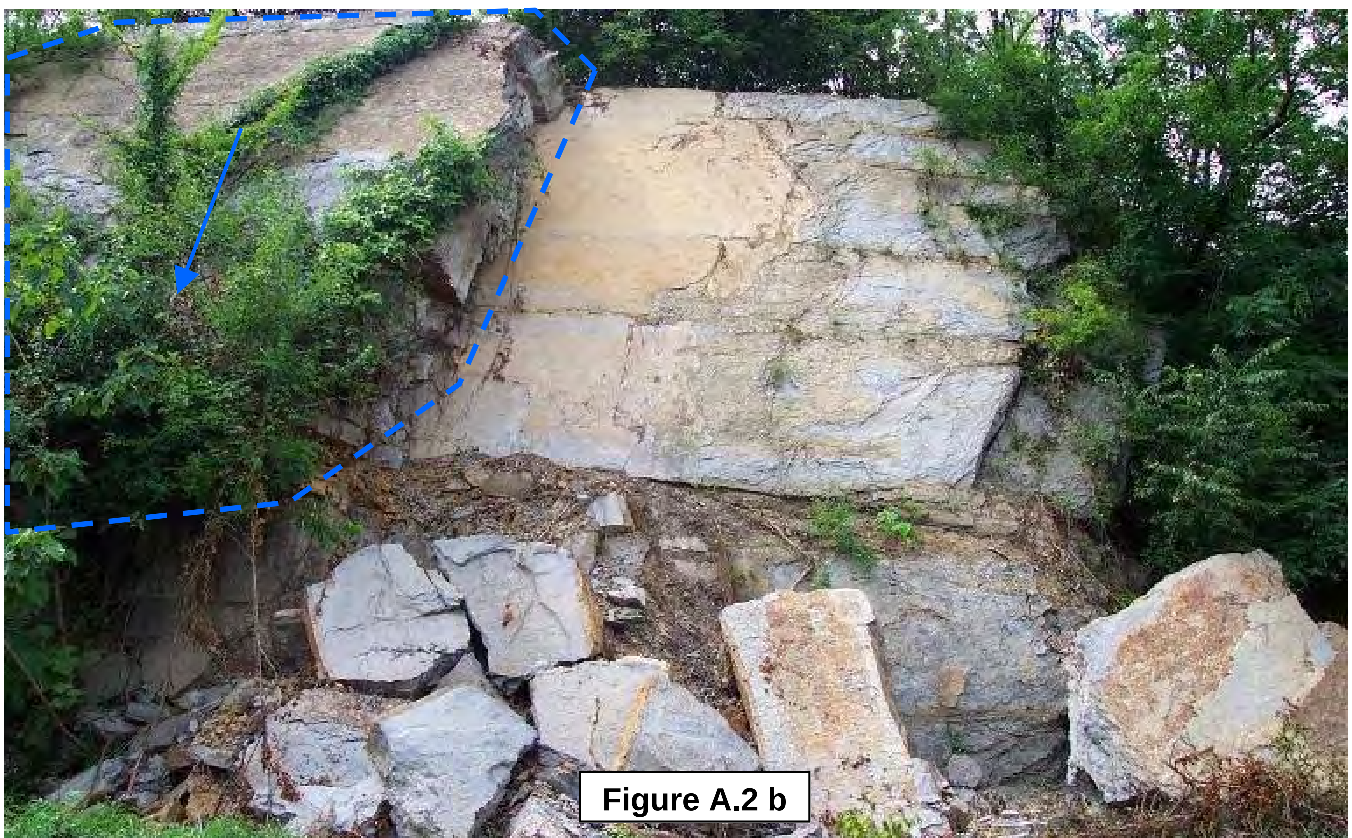
The following pictures show rock faces that exhibit characteristics for potential planar slide failure. Such characteristics are:

- Discontinuities dip towards and daylight on rock face
- Blocks have potential to slide on a single inclined plane or set of parallel inclined planes





Bedding planes of the rock face dip towards the roadway. Blocks enclosed in dashed lines have potential for planar slide along the bedding plane in the direction of the arrows. *(Hawkins County, SR 070, MM 16-10L)*



A sliding plane is exposed from past rock slides. Rock blocks on the top left of the slope (dashed line) are most likely to fail by sliding along the plane in the direction of the arrows. *(Knox County, I-40, MM 390-00L)*

Figure A.3 a

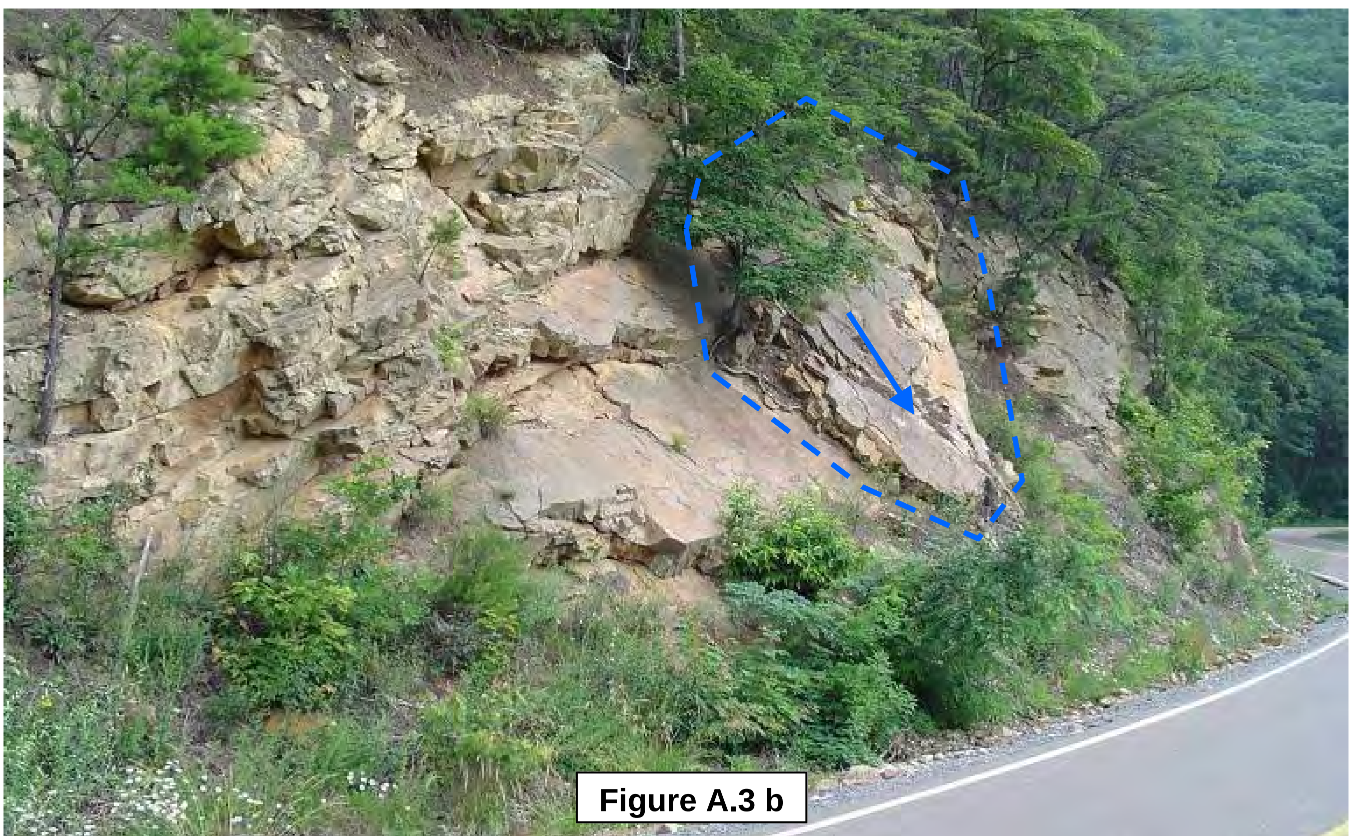


Figure A.3 b

This rock face exhibits potential for the blocks (dashed line) to slide along the bedding plane which is dipping towards the road. *(Sullivan County, SR 034, MM 33-20L)*

Figure A.4 a

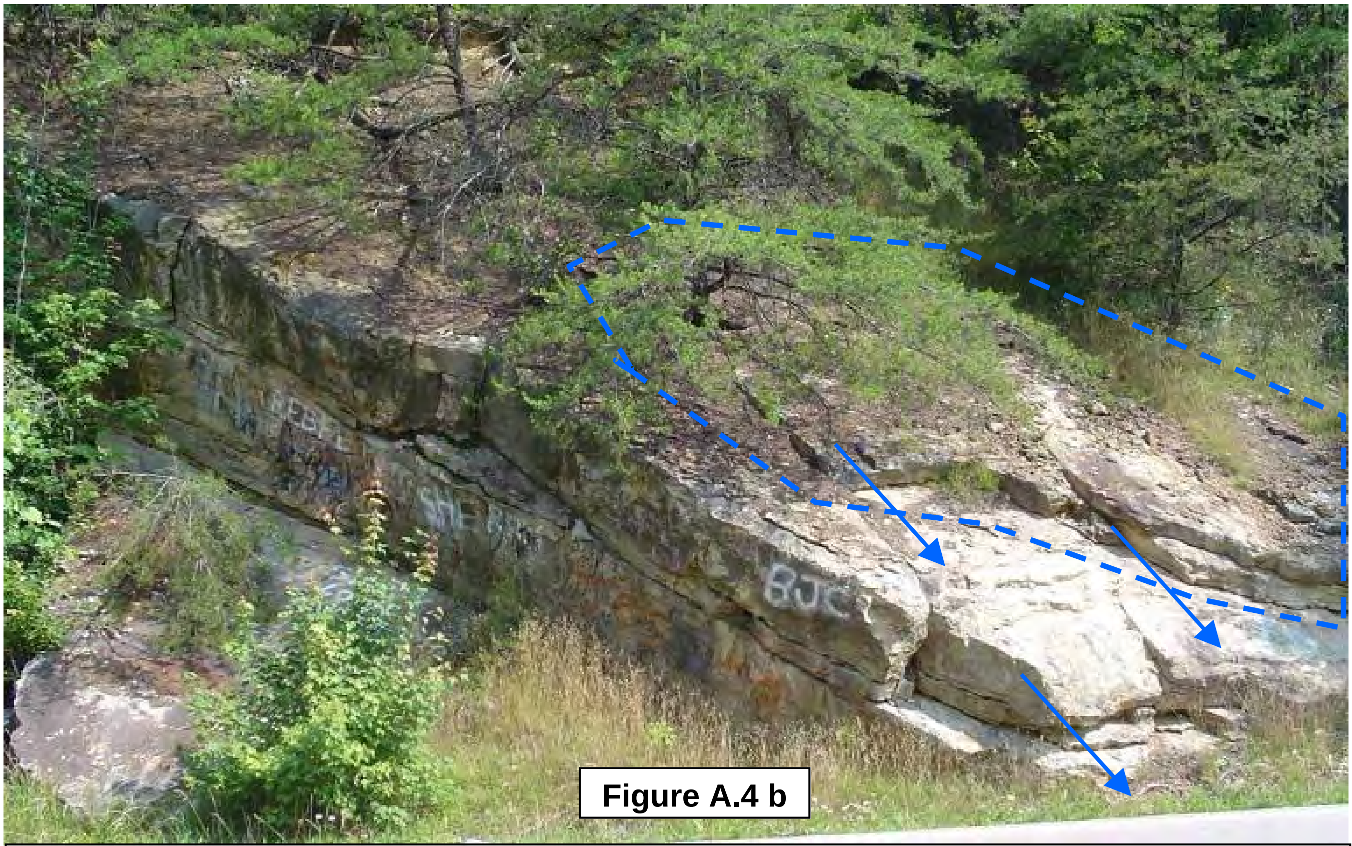


Figure A.4 b

In above rock face, a thin slab of rock blocks (dashed line) have potential to fail by planar slide in the direction of the arrows. Larger blocks around the thin slab are also subjected to potential planar slide failure. *(Hawkins County, SR 031, MM 6-60L)*

Figure A.5 a

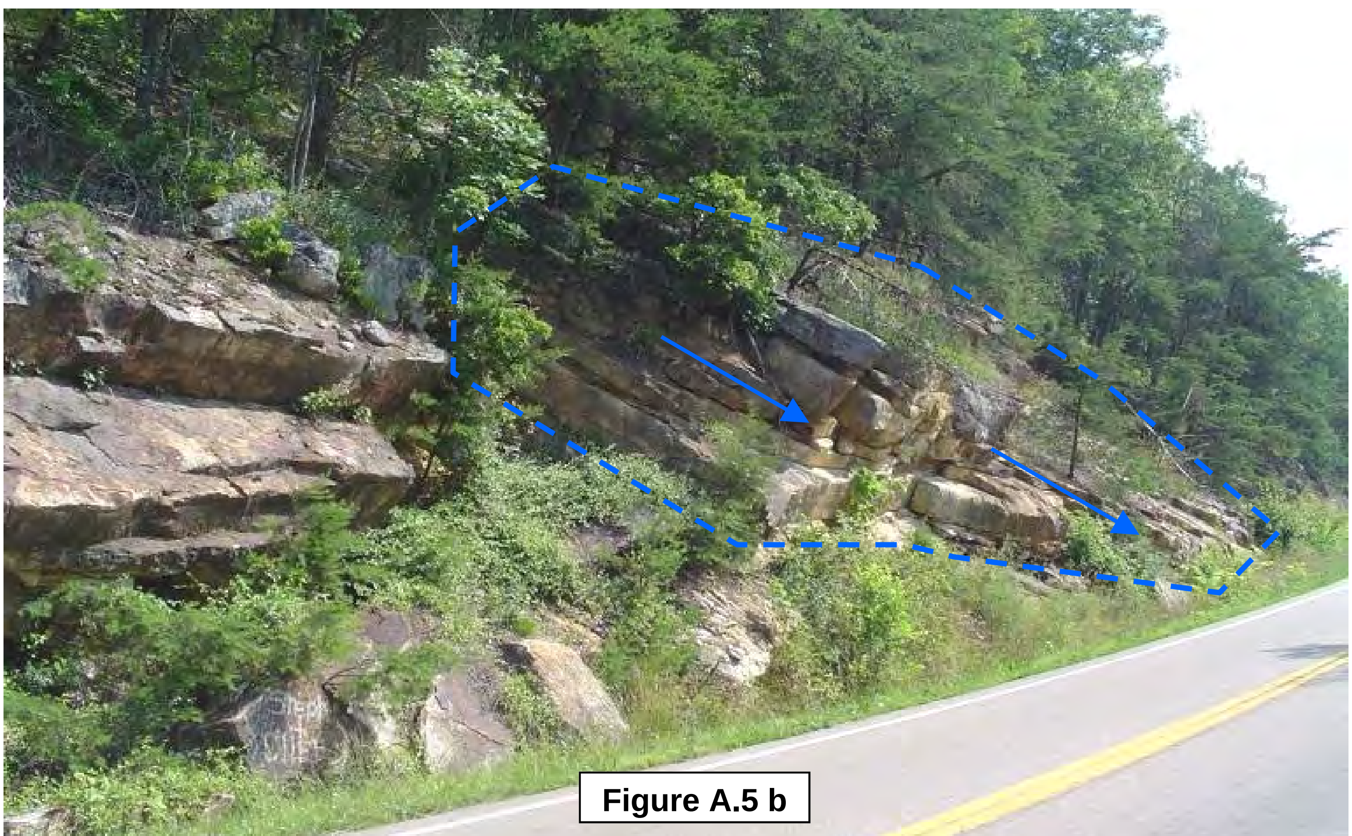


Figure A.5 b

This rock face shows parallel bedding planes that are dipping towards the roadway. Blocks enclosed in dashed line have potential to slide along the bedding plane into the road. *(Hawkins County, SR 031, MM 6-50L)*

Figure A.6 a

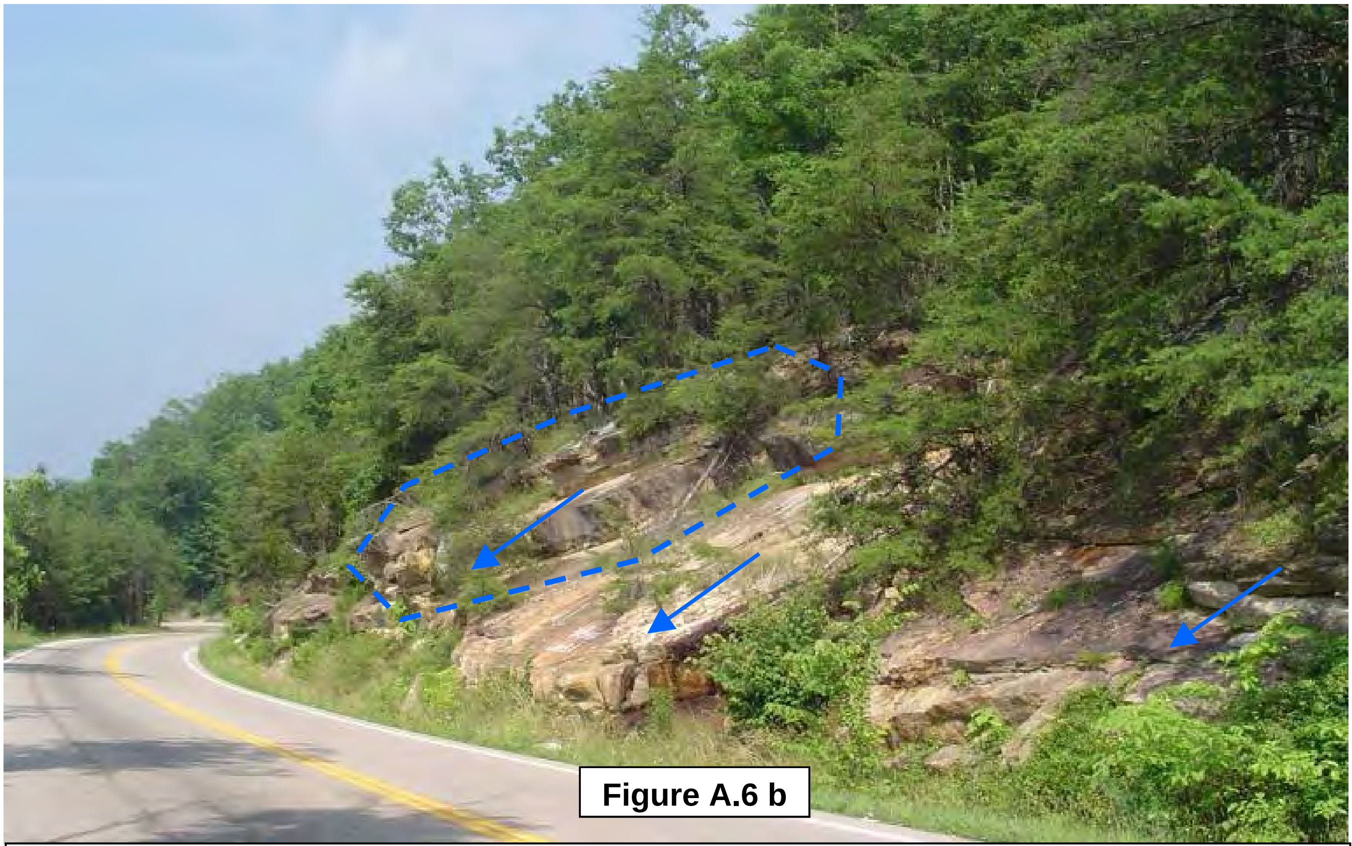
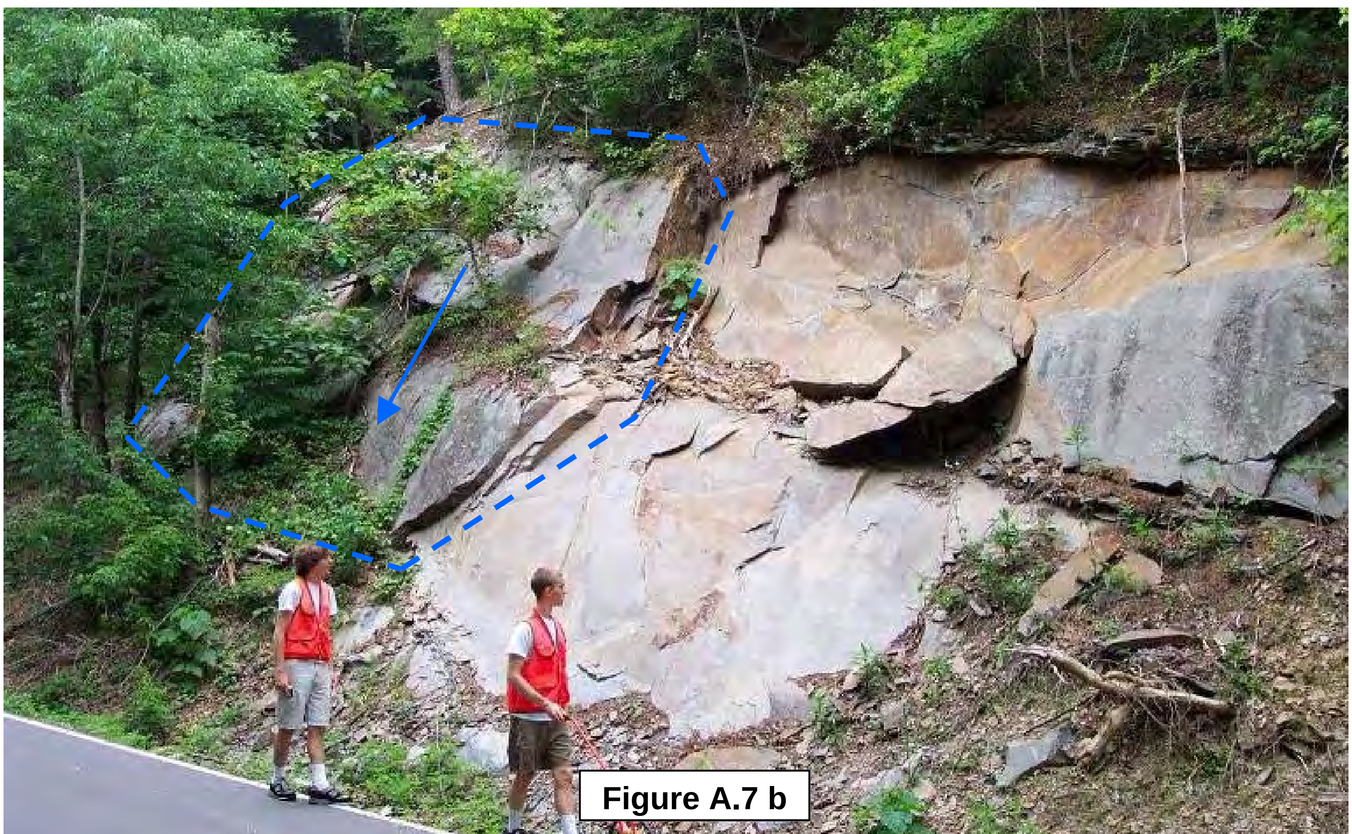


Figure A.6 b

Blocks enclosed in dashed line have potential to slide along the bedding plane towards the road. The rest of the slope is also subjected to planar slide failure.
(Hawkins County, SR 031, MM 6-40L)



A plane which dips into the road is exposed from the previous failures. Blocks, enclosed in dashed line, are likely to slide along the plane and into the road.
(Blount County, SR115, MM 4-00R)

Figure A.8 a

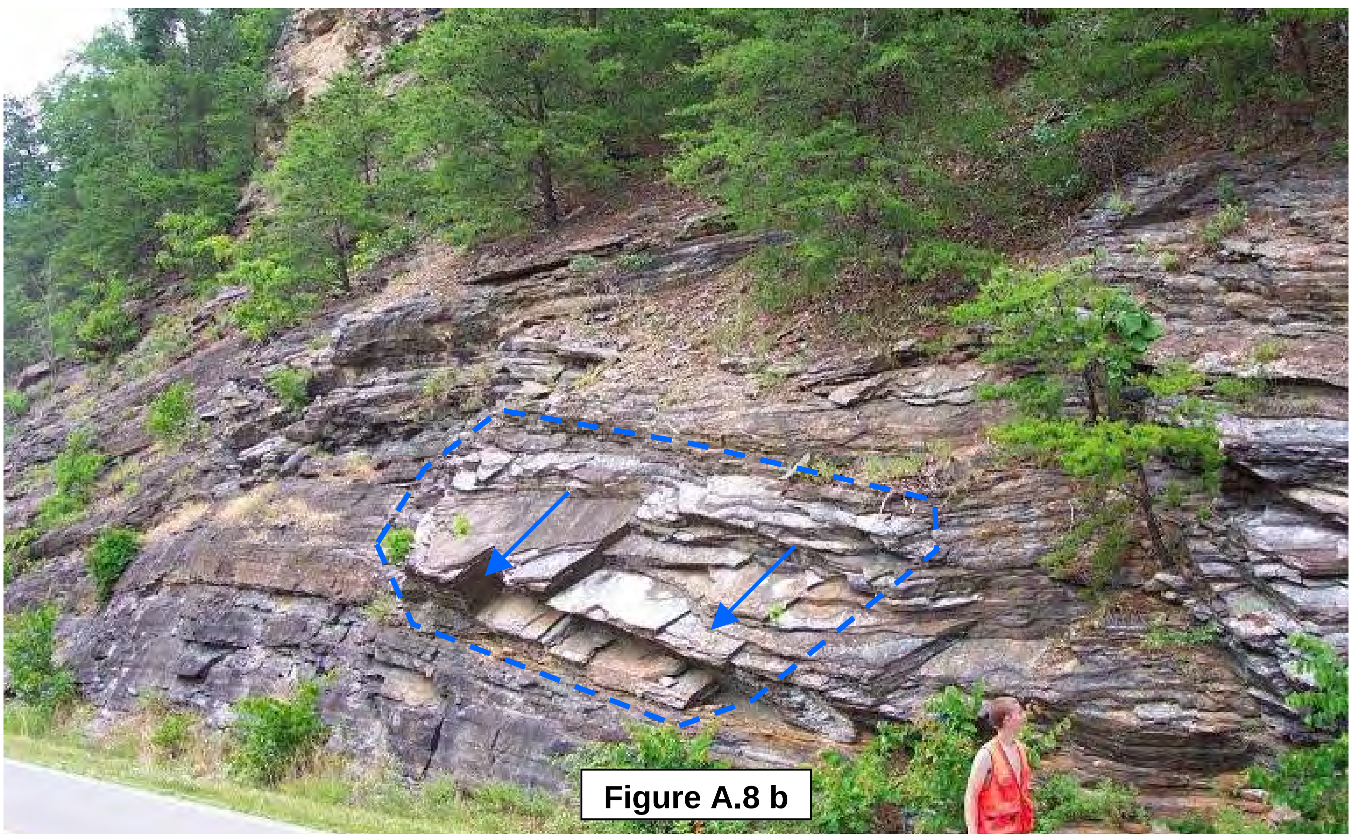


Figure A.8 b

Thin layers of blocks (dashed line) have potential to fail and slide in the direction of the arrows.
(Blount County, SR115, MM 16-40R)

Figure A.9 a

Figure A.9 b

The entire slope shown above is subjected to potential planar slide failure.
(Carter County, SR159)

Figure A.10 a

Figure A.10 b

Blocks enclosed in dashed line have potential to fail and slide onto the road. The rest of the slope is also subject to planar sliding.
(Johnson County, SR 034, MM 19-60L)

Chapter 1.2:

Wedge Slide Failure

Wedge slide failure is characterized by two intersecting sliding planes, oriented such that sliding blocks maintain contact with both faces and have the potential to reach the roadway

The following pictures show rock faces that exhibit characteristics for potential wedge slide failure. Such characteristics are:

- Line of intersection of surfaces plunges toward roadway and daylights on rock face
- Blocks have potential to slide simultaneously on two or more inclined non-parallel surfaces

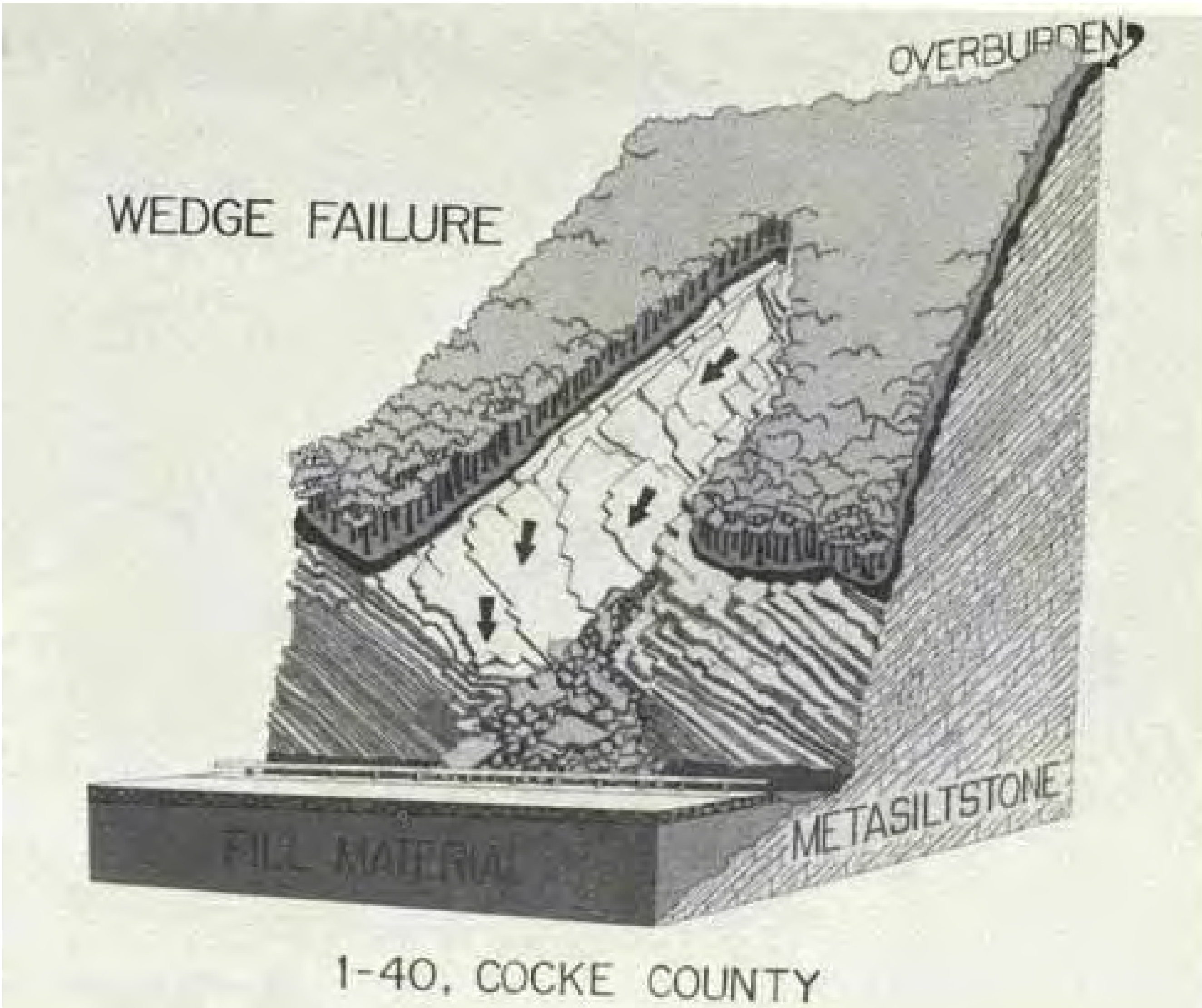


Figure B.1

Illustration of the wedge failure which occurred along I-40 in Cocke County, Tennessee in 1976. The steeply inclined slope consists of highly jointed strata of metasiltstone and meta-sandstone. Two directions of jointing can be observed on this slope: one forming the right-hand side of the wedge and the other subparallel to the slope face. The wedge failure had developed along bedding and the first of the above-mentioned joint sets.

*Figure from *Landslide Remedial Measures* by Royster, David L., 1982.

Figure B.2

Aerial view of a large scale wedge slide which occurred in July 1976 along I-40 in Cocke County, Tennessee. The failure is shown schematically in the previous figure.

*Figure from *Landslide Remedial Measures* by Royster, David L., 1982.

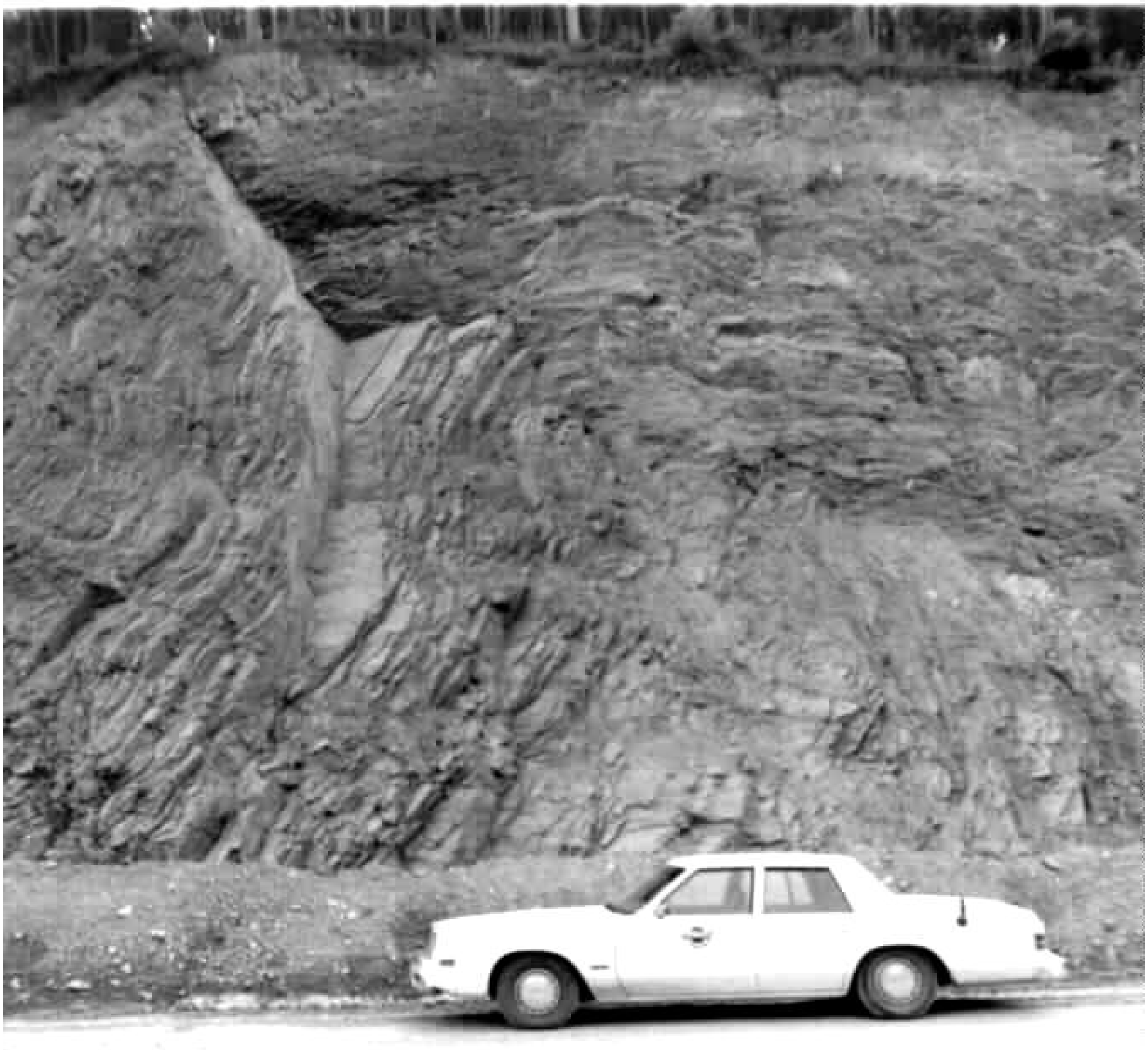


Figure B.3

This rock mass exposes the mold of a failed wedge, just forward of the car. The wedge failure is bounded by two non-parallel discontinuity sets, one of which is bedding. The line of intersection of the two planes dips towards the roadway. This slope has the potential for future wedge failures.

*Figure from *Wedge Failures along Tennessee Highways in the Appalachian Region: Their Occurrence and Correction* by Moore, Harry L.., 1986.

Figure B.4

A significant wedge slide occurred on July 4th, 1997 along I-40 near the Tennessee—North Carolina boarder. Two non-parallel discontinuities can be seen on the slope face (dashed line).

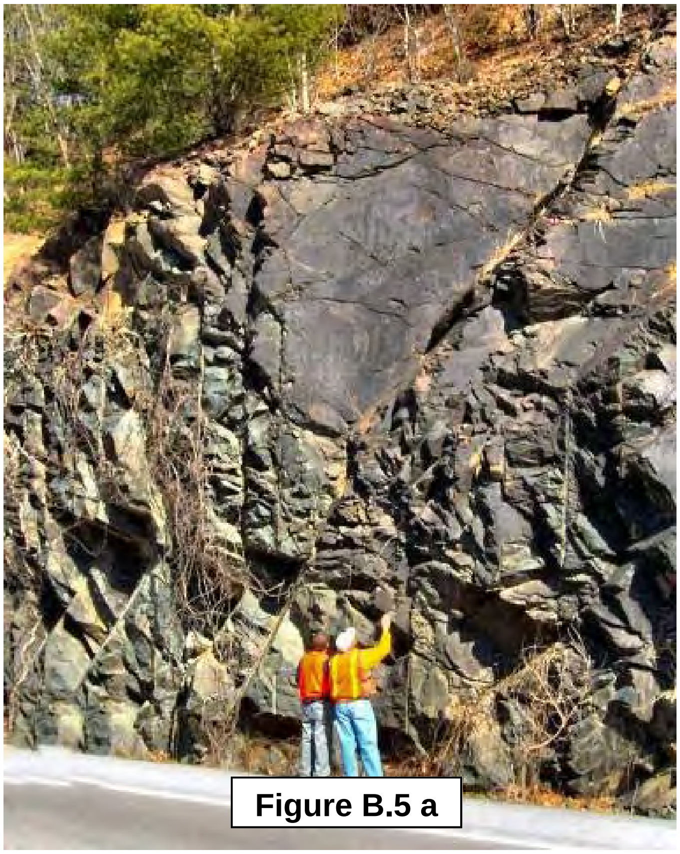


Figure B.5 a

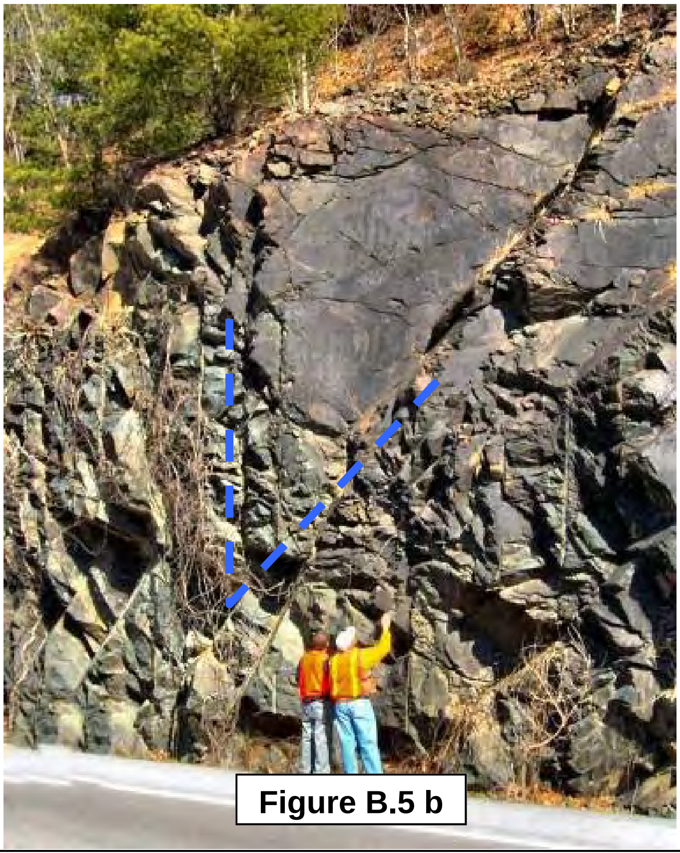


Figure B.5 b

This rock slope shows two intersecting sliding planes with the intersecting line dipping towards the roadway. An example of a rock block with the potential to fail by sliding on two sliding planes is indicated by the dashed line.
(Carter County, SR 037, MM 14-10R)

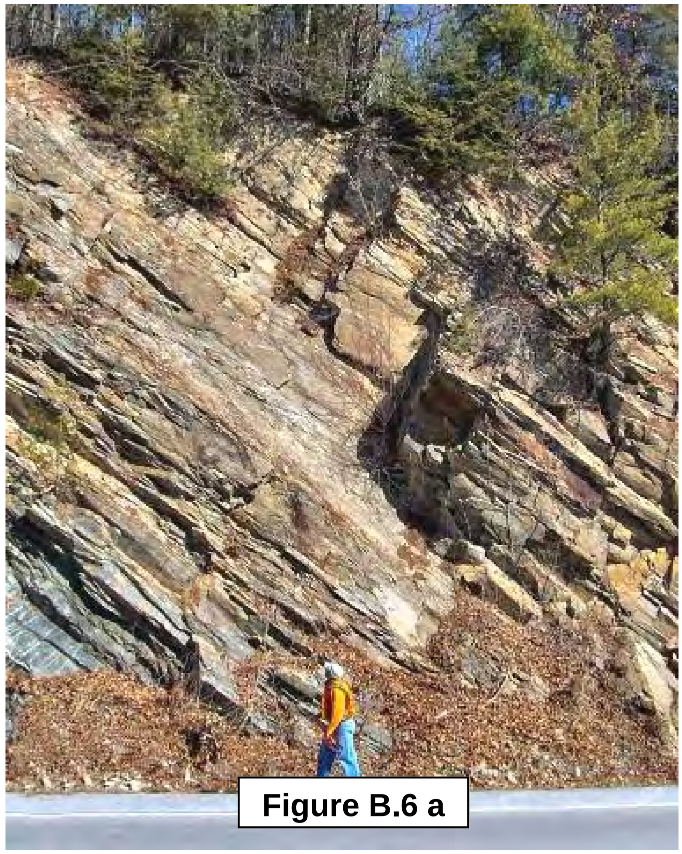


Figure B.6 a

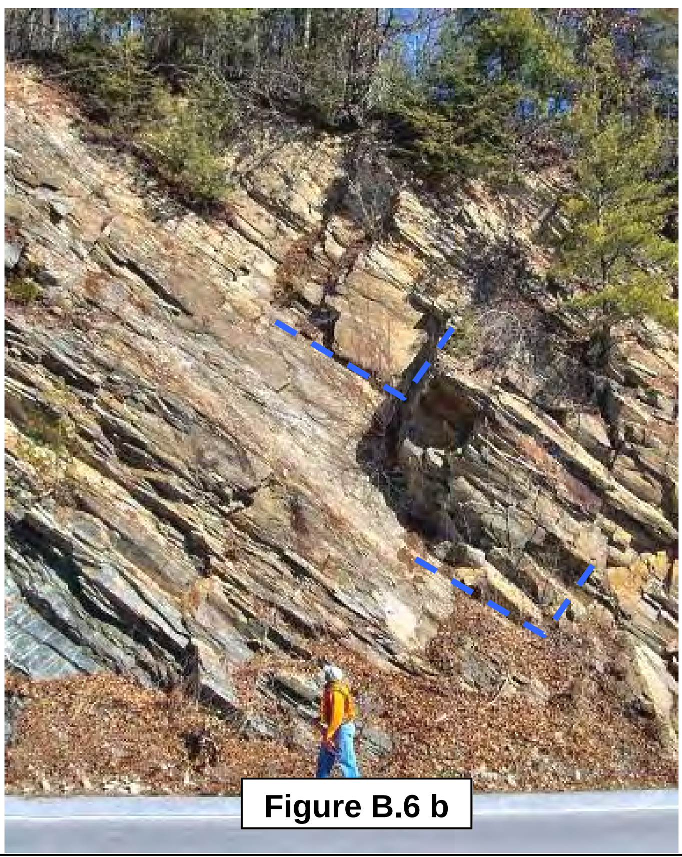


Figure B.6 b

This rock slope shows two non-parallel sliding planes on which rock blocks could slide. The line of intersection of the two planes dips towards the road. The dashed lines indicate the orientation of the two sliding planes and the rock blocks above the dashed lines have the potential to fail by wedge sliding.
(Carter County, SR 037, MM 7-50R)

Figure B.7 a

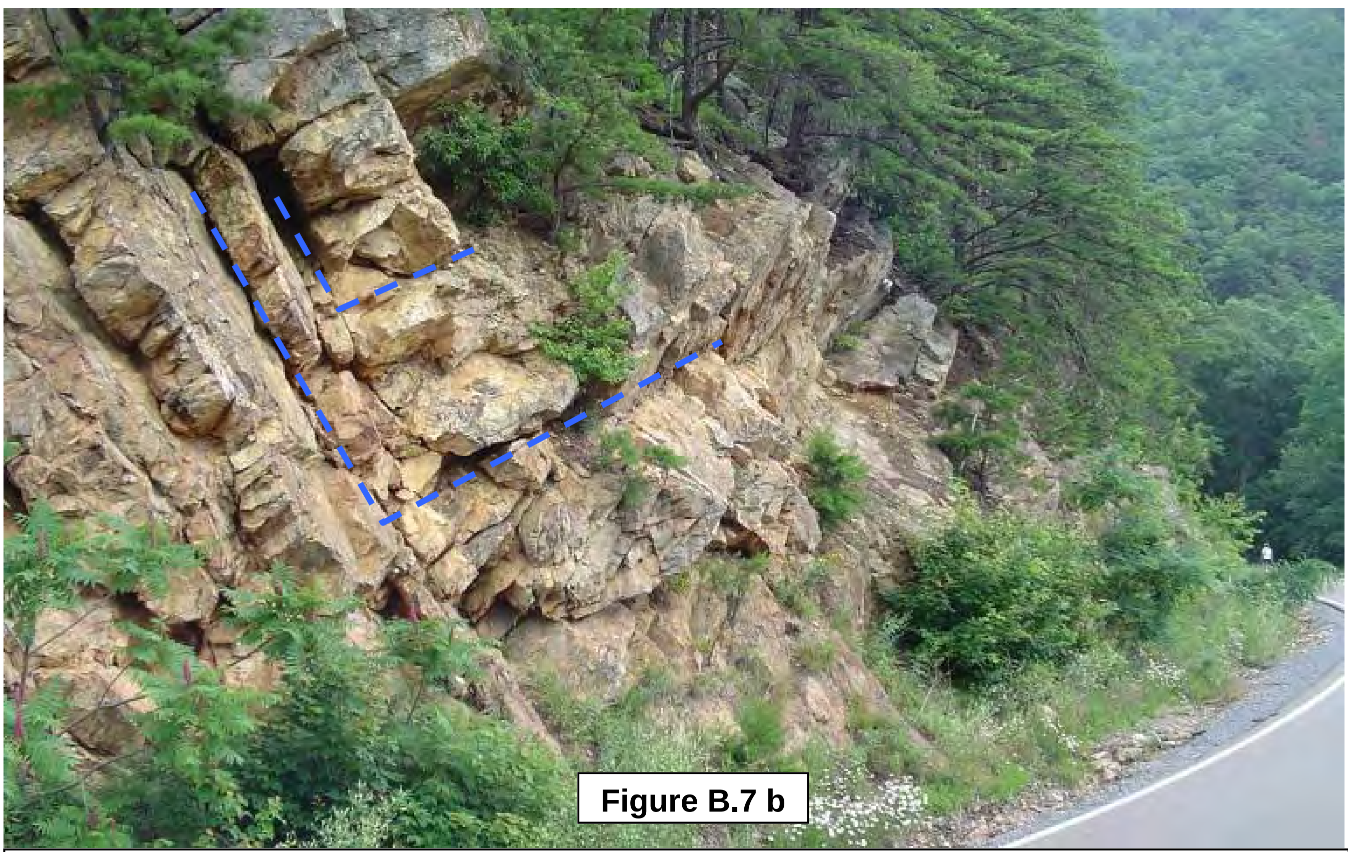


Figure B.7 b

Two non-parallel planes which rock blocks may slide on can be seen at this rock cut. The line of intersection of the two planes dips towards the roadway. The dashed lines mark the orientation of the two sliding planes and examples of rock blocks (or aggregates of rock blocks) with the potential to fail by wedge sliding.
(Sullivan County, SR 034, MM 33-20L)

Figure B.8 a

Figure B.8 b

This rock slope consists of non-parallel sliding planes on which rock blocks may slide and reach the roadway. The orientation of these sliding planes is marked by the dashed lines. Examples of the blocks with the potential for wedge slide is also marked by the dashed lines.

(Blount County, SR 115, MM 15-00R)

Figure B.9 a

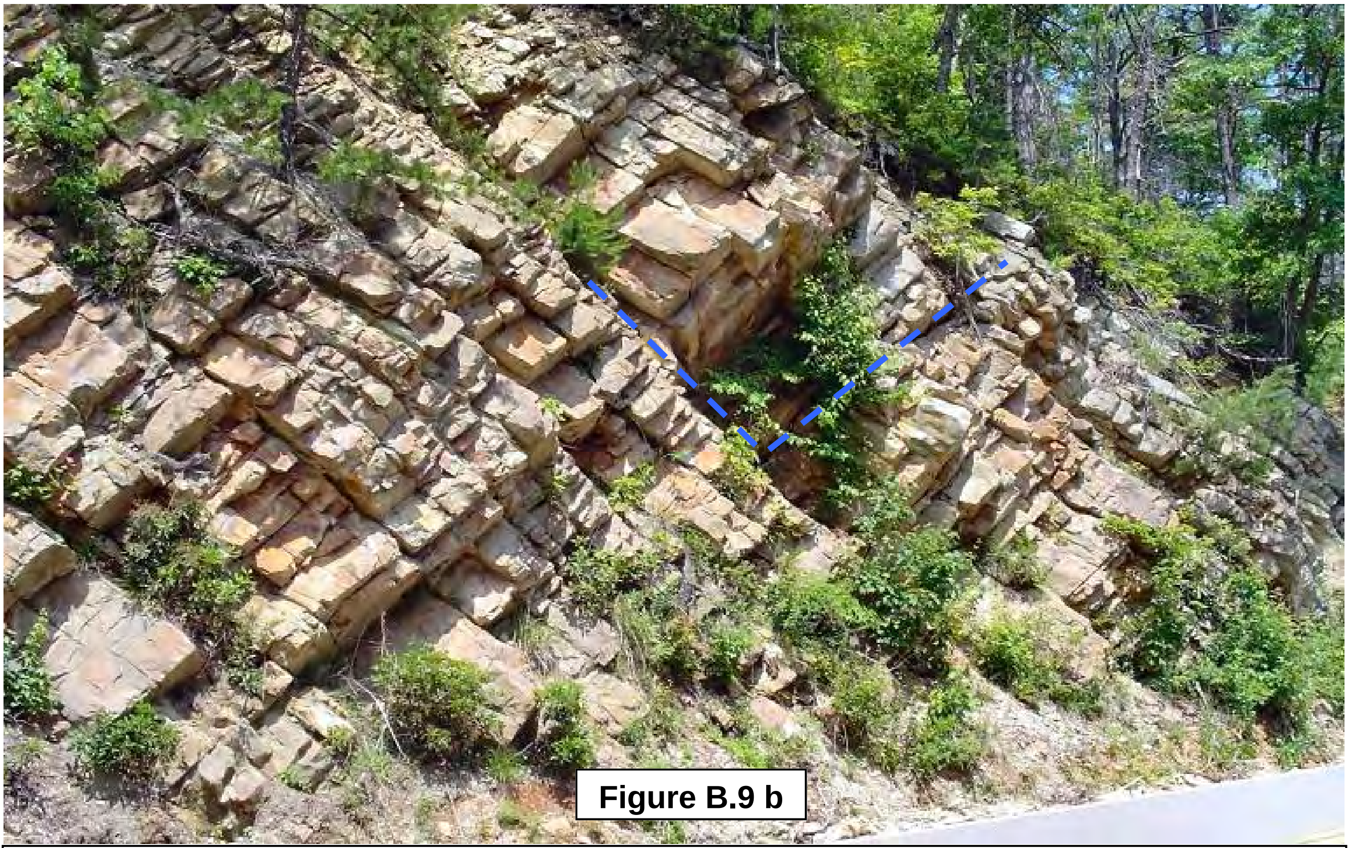


Figure B.9 b

The rock slope face is highly fractured and consists of small blocks which have the potential to slide on two non-parallel sliding planes and onto the roadway. The dashed lines mark examples of rock blocks (or aggregates of rock blocks) with the potential to fail by wedge sliding.
(Sullivan County, SR 034, MM 33-70L)

Figure B.10 a

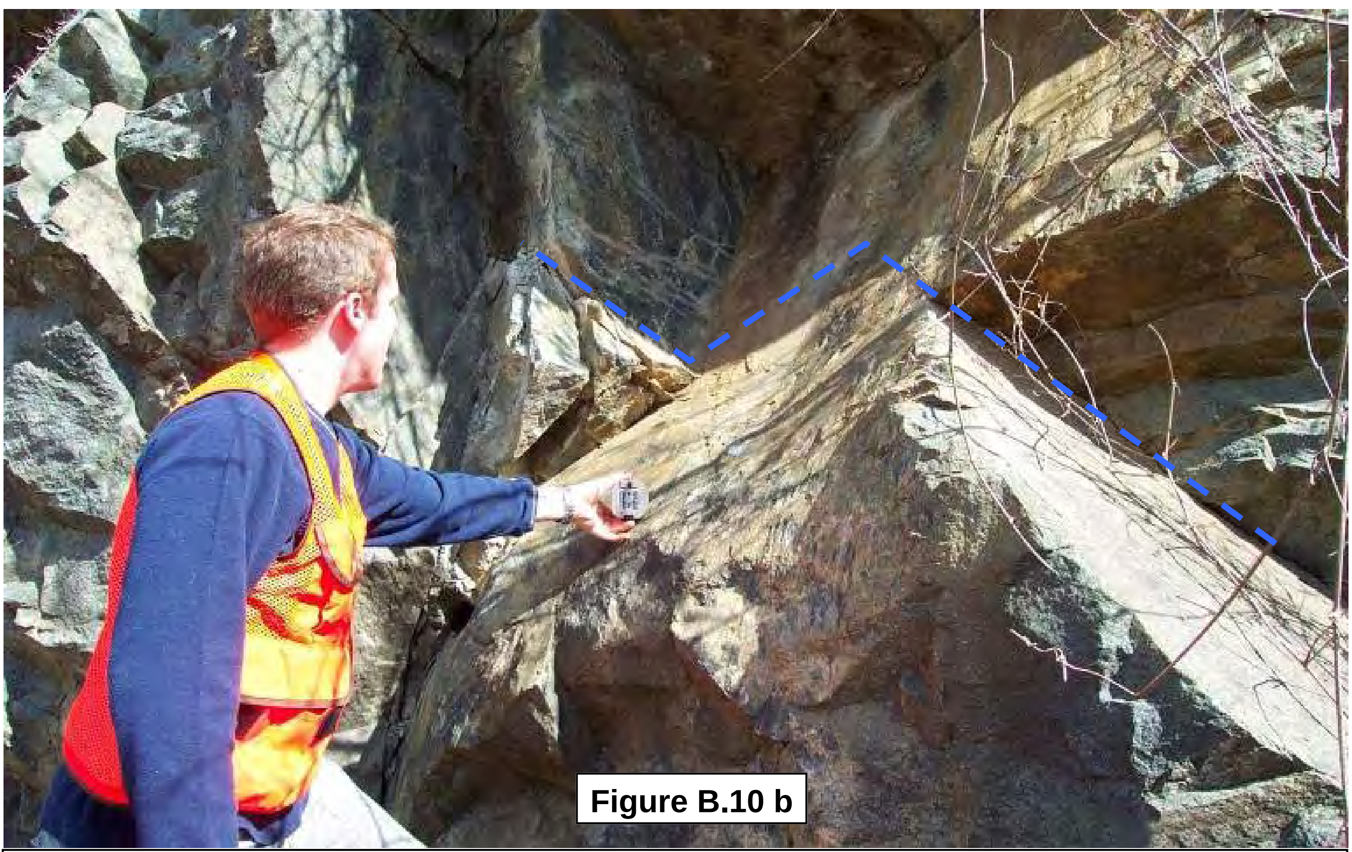


Figure B.10 b

Two distinct non-parallel planes can be seen on this rock slope. The line of intersection of the planes dips towards the roadway (foreground). The orientation of the two planes is indicated by the dashed line. The rock blocks at this cut have the potential to fail by wedge sliding.
(Carter County, SR 037, MM 14-10R)

Chapter 1.3:

Topple Failure

Topple failure involves forward rotation of rock slabs or layers. The special case of block release from horizontally bedded rock is included under topple.

The following pictures show rock faces that exhibit characteristics for potential topple failure. Such characteristics are:

- Rock mass is layered, with layers striking sub-parallel to road and dipping away from road, or with layers horizontal
- Potential movement is forward rotation

Figure C.1 a

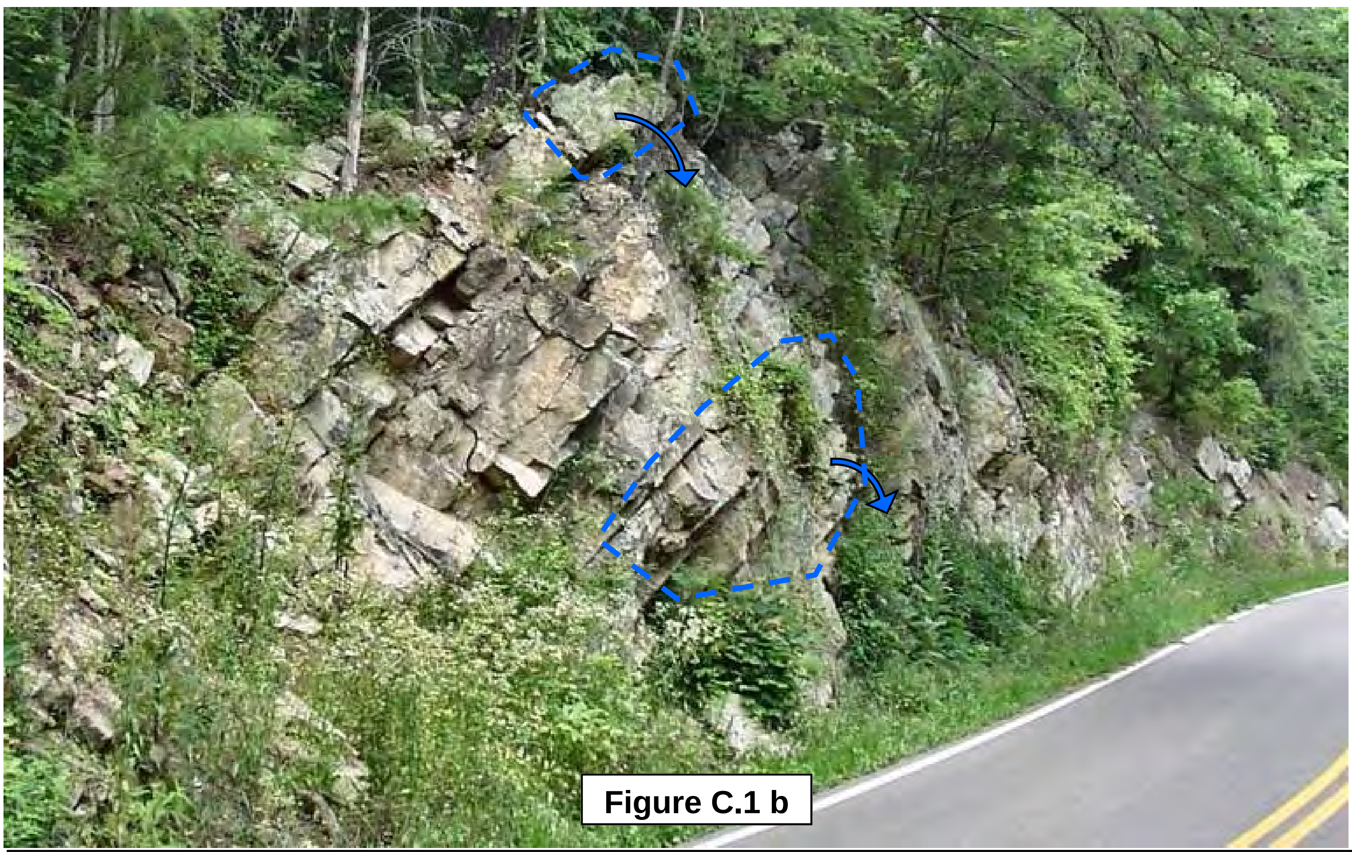


Figure C.1 b

Rock mass is layered with layers dipping away from the road. Examples of bedded rock slabs (inside dotted lines) with potential to rotate out and reach the road are indicated. *(Hawkins County, SR 347, MM 8-52L)*

Figure C.2 a

Figure C.2 b

This rockcut shows a layered rock mass which dips away from the road. The dotted lines indicate examples of rock slabs with potential to fail by rotating out and onto the road. *(Johnson County, SR 034, MM 7-30L)*

Figure C.3 a

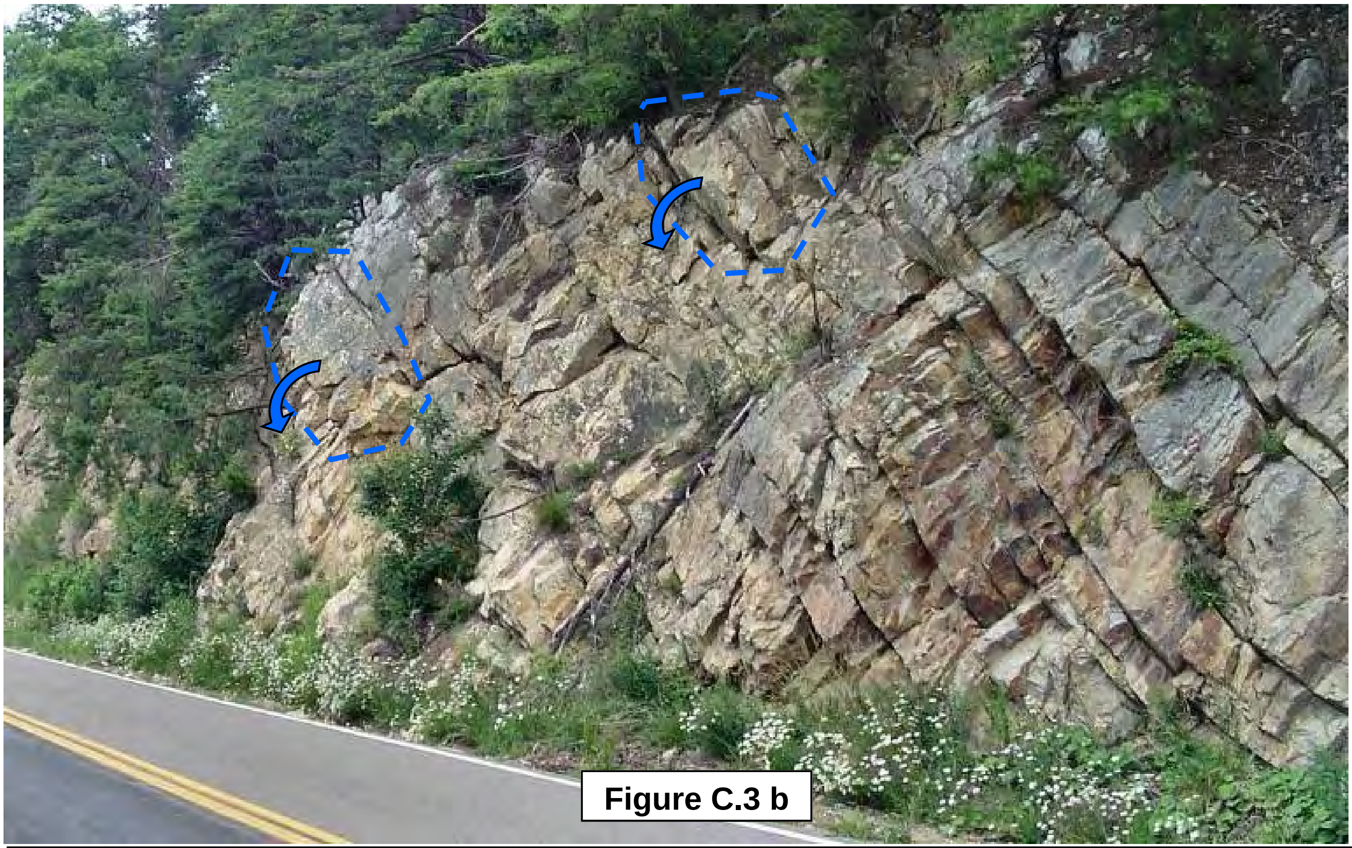


Figure C.3 b

The rock mass is layered with layers dipping away from the road. The dotted lines indicate examples of rock slabs with potential to fail by forward rotation and reach the road. *(Sullivan County, SR 034, MM 33-20L)*

Figure C.4 a

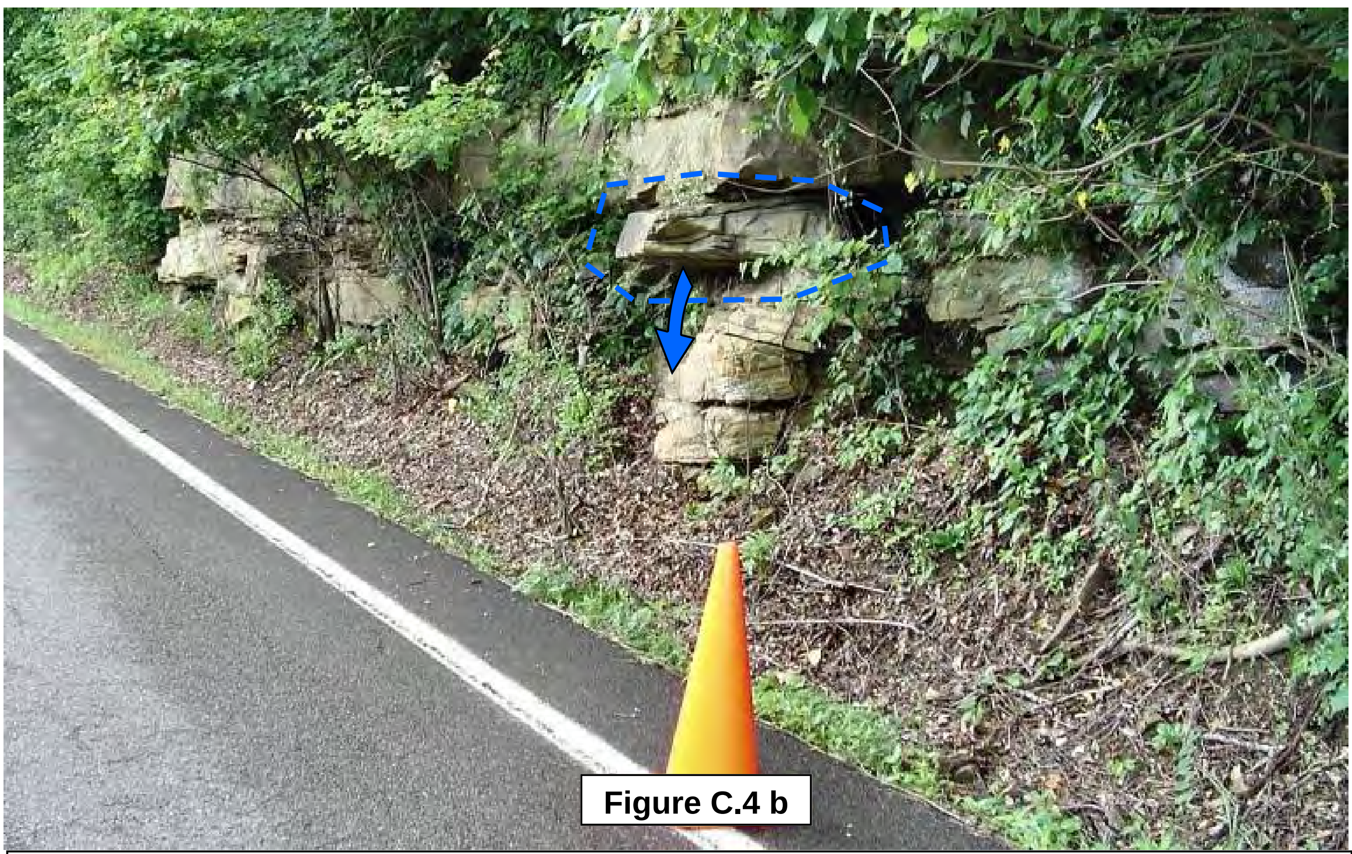


Figure C.4 b

Rock mass above shows sub-horizontal beds. An example of a rock slab with sufficient local relief to fail by block release is indicated. For the purpose of the TDOT RHRS, block release is considered a special case of toppling failure.
(Campbell County, SR 009, MM 12-60)

Figure C.5 a

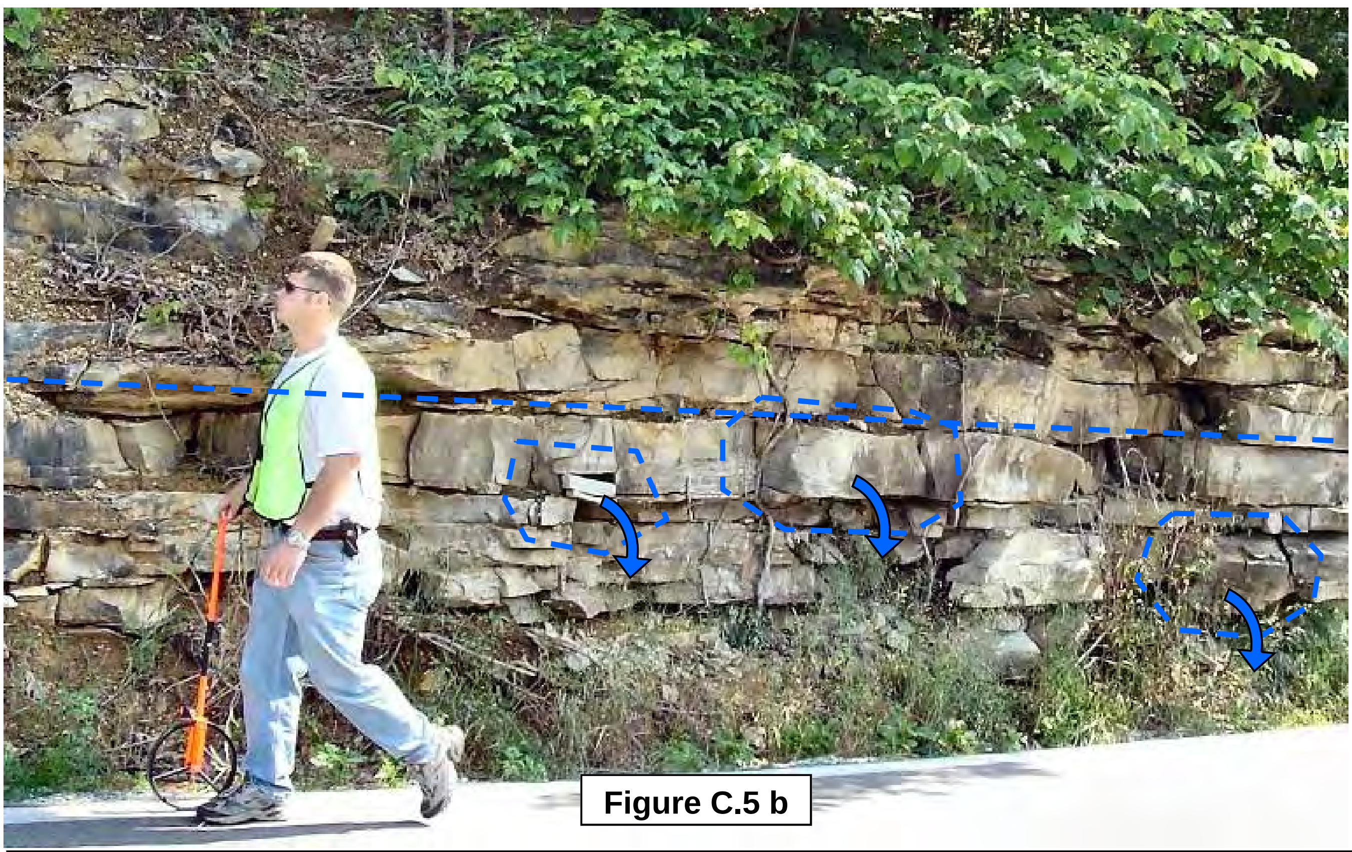


Figure C.5 b

Rock mass is bedded, with near horizontal layers. Rock slabs circled with dotted lines, and smaller rock blocks throughout the rock face, have potential to fail by block release. Because of the visible loosening, however, as indicated by wide fracture apertures, the entire face up to the straight dotted line is considered prone to topple failure.
(Claiborn County, SR 063, MM 27-30 L)

Figure C.6 a

Figure C.6 b

Bedding dips away from the road. Examples of slabs with potential to fail by rotating out and onto the road are indicated. Smaller blocks throughout the rock face also have potential to rotate out and reach the road.
(Washington County, SR 081, MM 00-30R)

Figure C.7 a

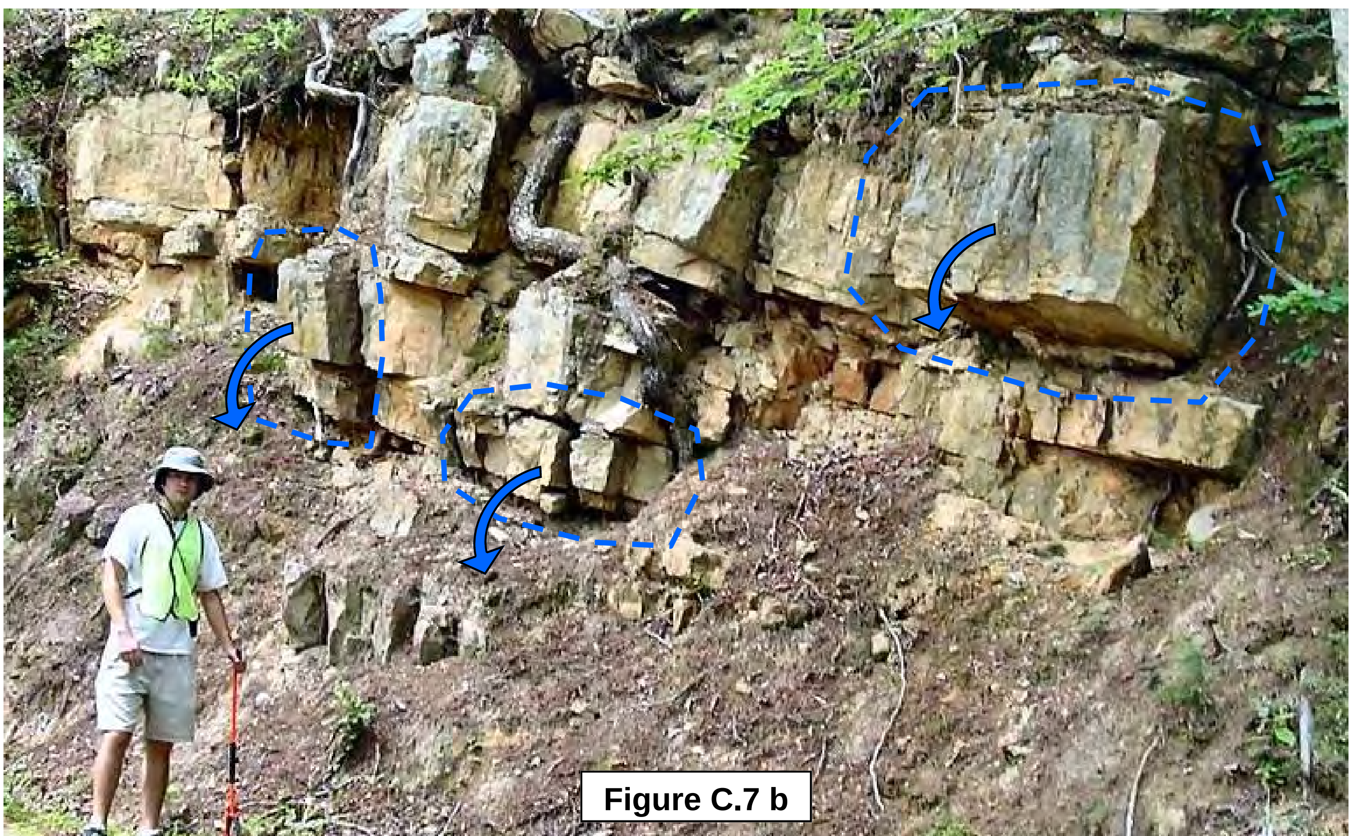


Figure C.7 b

This rock cut exposes large blocks which have potential to rotate out and reach the road (which is left-right, in the foreground). Bedding dips primarily to the right in this picture, but a component of the dip is directed away from the road.
(Hawkins County, SR 066, MM 23-80R)

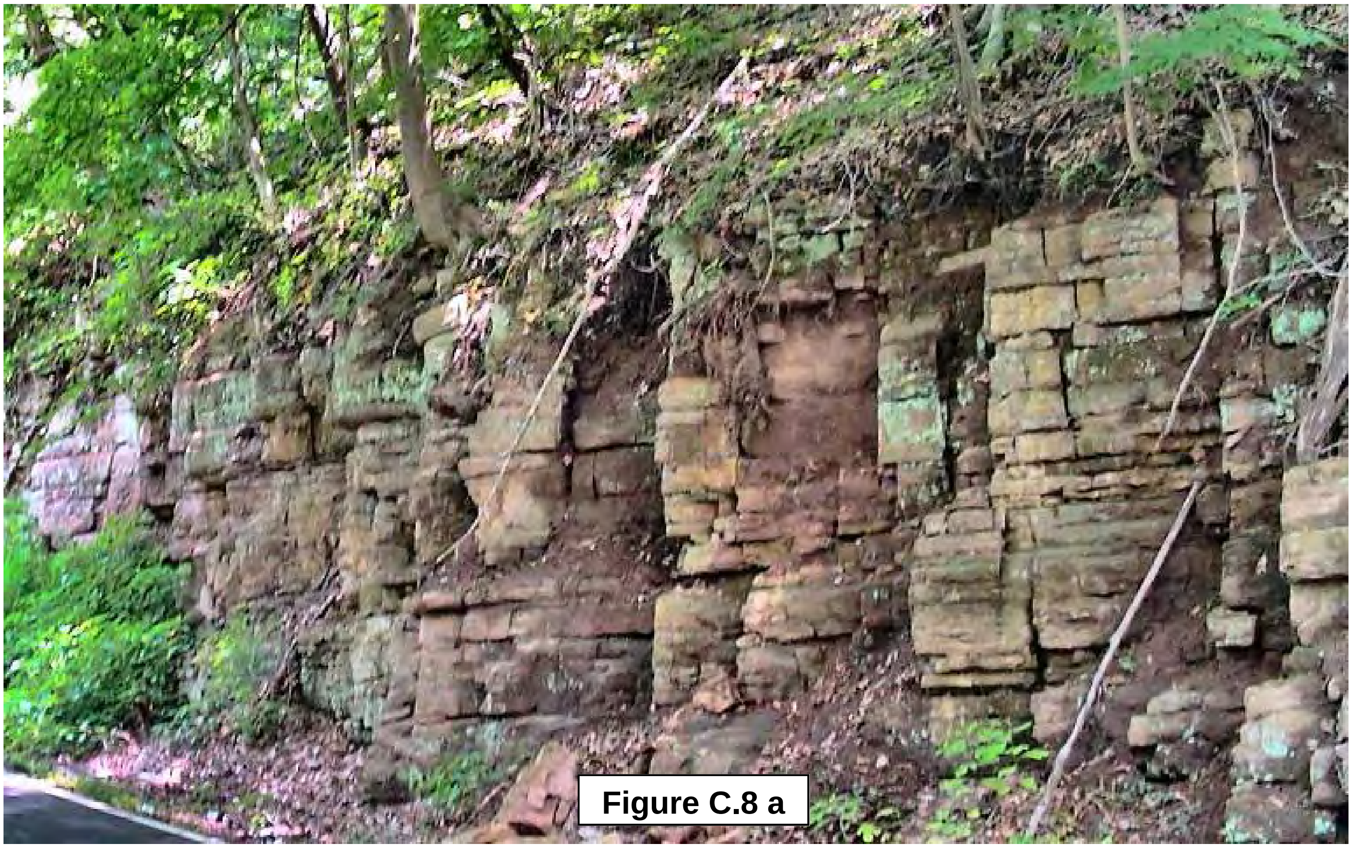


Figure C.8 a

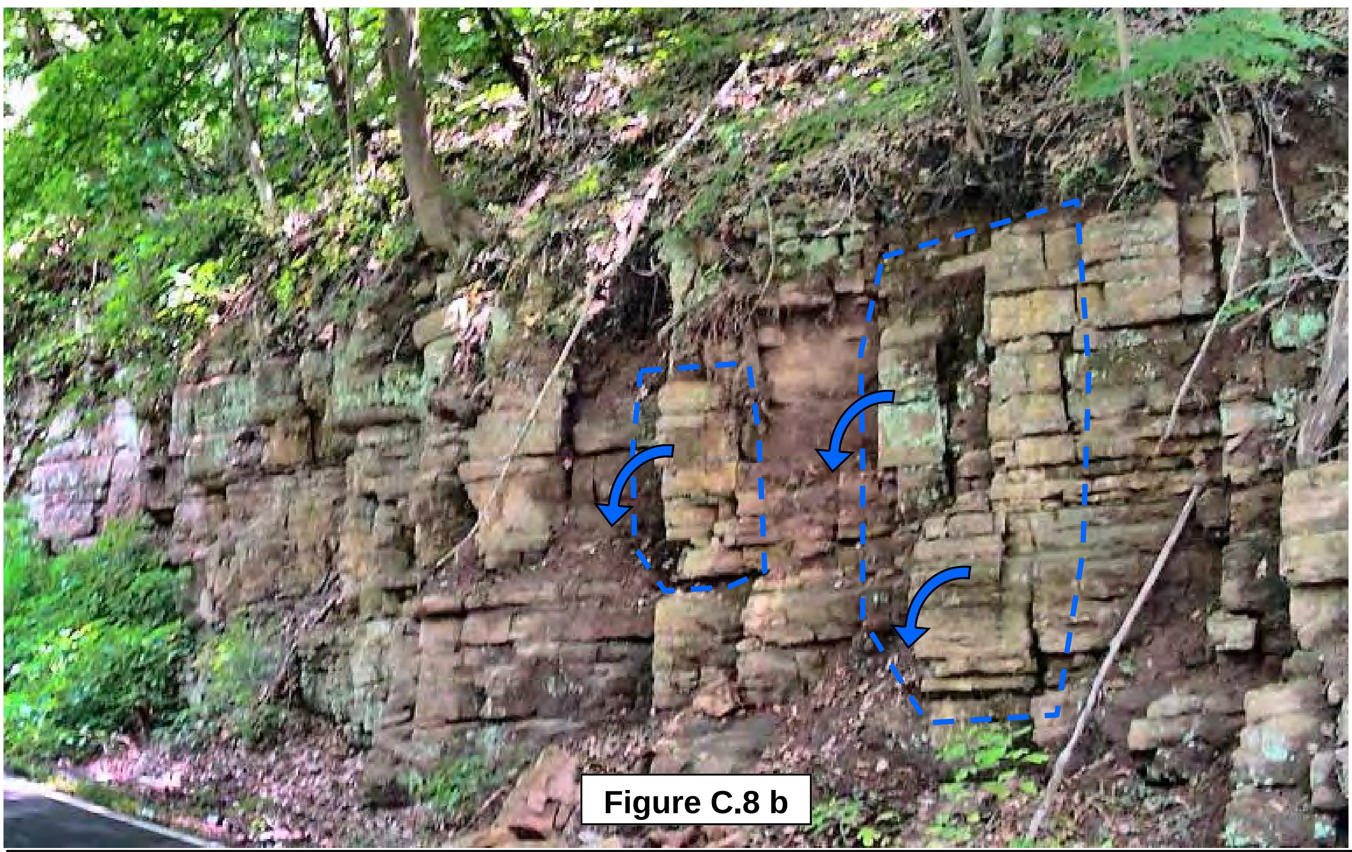


Figure C.8 b

Bedding at this rock face dips slightly towards the road. However, the slope is subject to toppling failure with the potential to place rocks on the road. Toppling is controlled by a steeply inclined fracture set with a component of dip away from the road. Although this is not a classic example of toppling, this fracture set (in conjunction with a second sub-vertical fracture set) produces columns of rock susceptible to toppling failure by outward rotation. *(Hawkins County, SR 347, MM 6-38R)*

Figure C.9 a

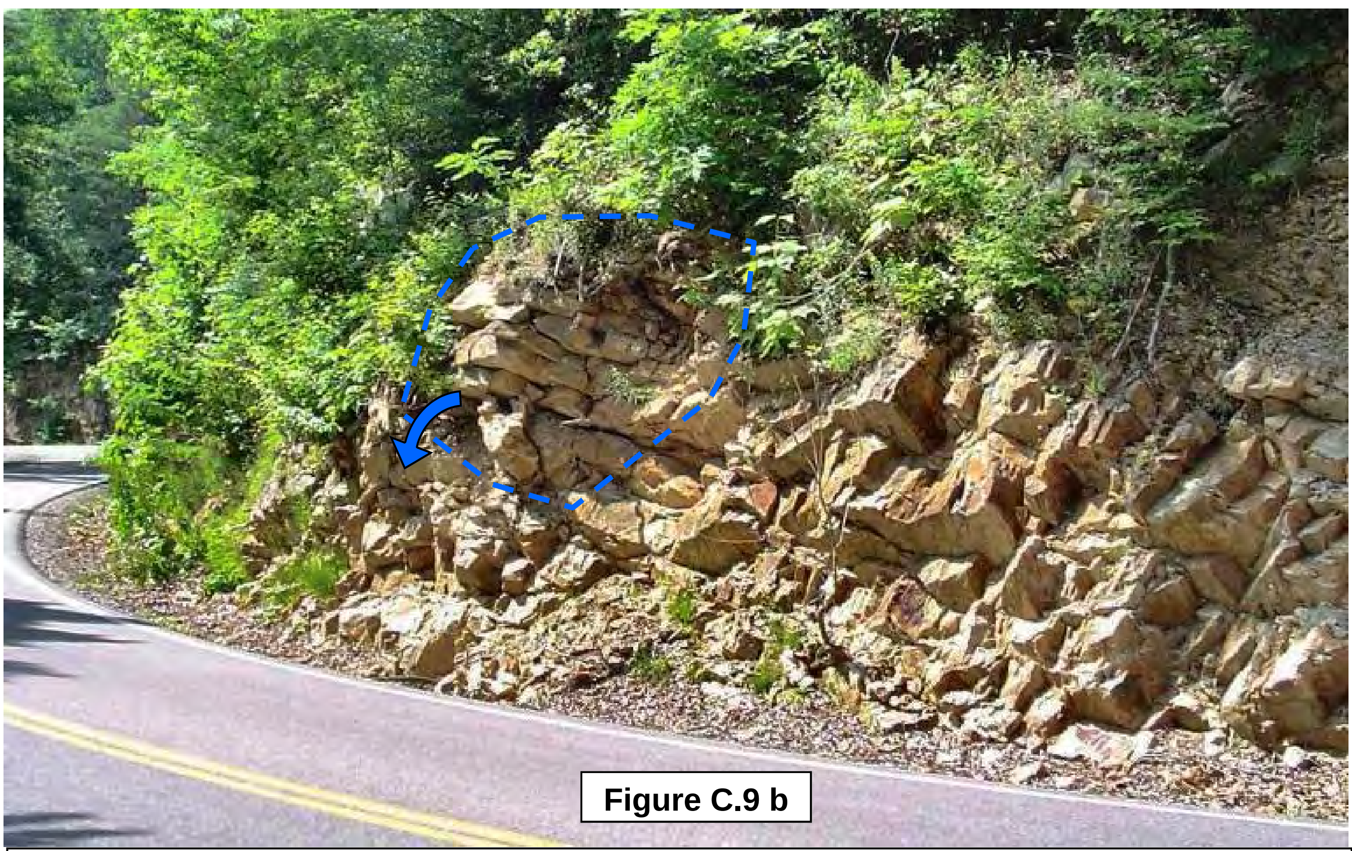


Figure C.9 b

Examples of rock slabs, outlined by dotted line, show potential to fail and rotate forward onto the road.
(Johnson County, SR 034, MM 6-30L)

Figure C.10 a

Figure C.10 b

The rock mass above consists of layers that are dipping away from the road. A rock slab outlined by dotted line has potential to rotate out and fall onto the road. Because of pronounced relief, the rest of the slope is also subjected to topple failure.
(Carter County, SR 159)

Chapter 1.4:

Differential Weathering

Differential weathering occurs in rock slopes with adjacent lithologies that have different weathering characteristics, and therefore erode at different rates. A common example is a rock slope with sandstone or limestone overlying shale. The shale erodes back, leaving the more resistant sandstone or limestone with an overhang. Differential weathering is usually accompanied by one or more structural failure modes, commonly toppling.

The following pictures show rock faces with characteristics for potential failure due to differential weathering. Such characteristics are:

- Rock mass exhibits non-uniform weathering characteristics and localized relief
- Weathering contrasts create potential for blocks to fall

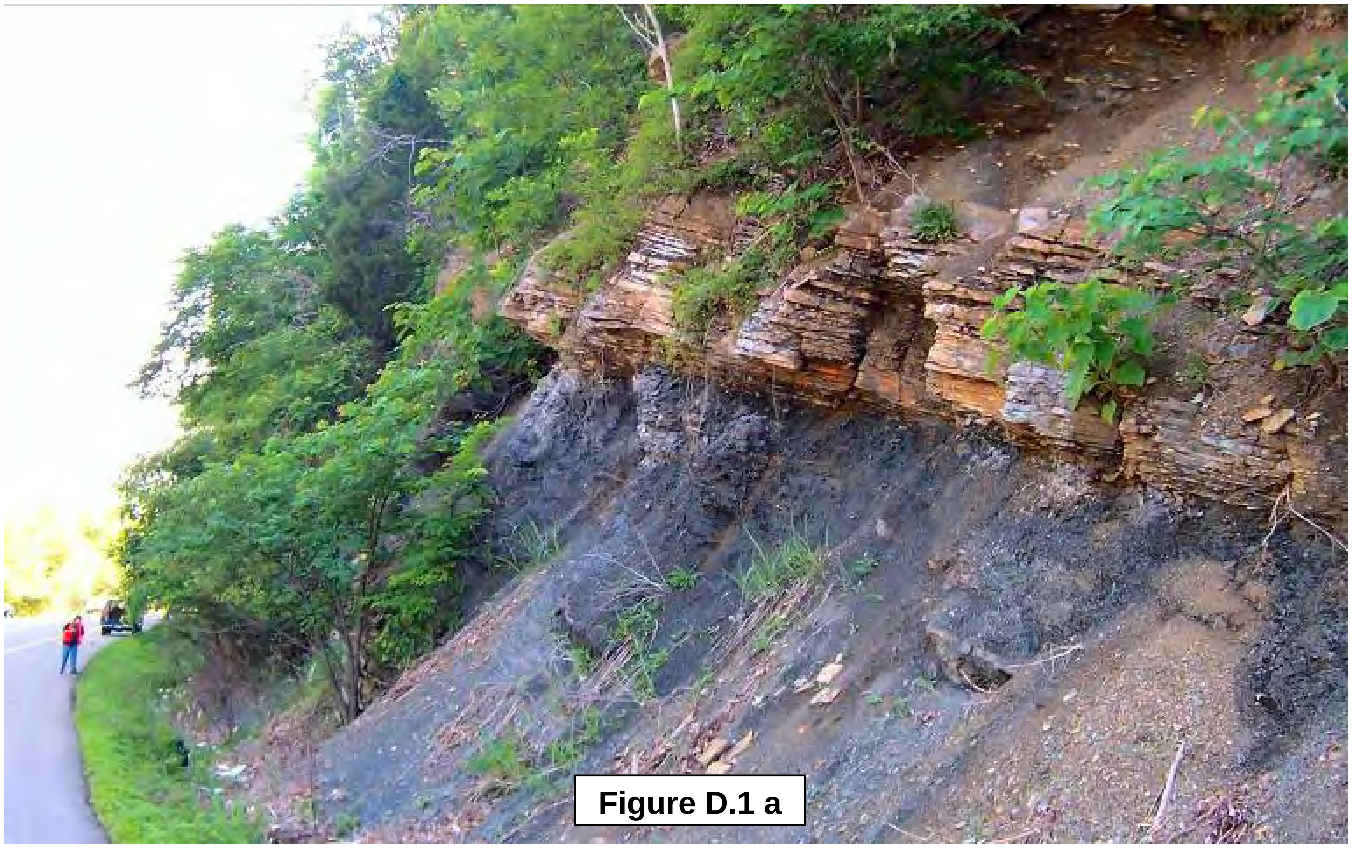


Figure D.1 a

Figure D.1 b

This rock slope shows two lithologies with the lower unit eroding faster than the upper unit. An overhang, created by the difference in erosion rates, can be seen throughout the slope along the boundary between the two units (dashed line). Progression of the differential erosion will lead to loss of support of the more resistant unit which will lead to potential rock failure. *(Knox County, SR 033, MM 19-80R)*

Figure D.2 a

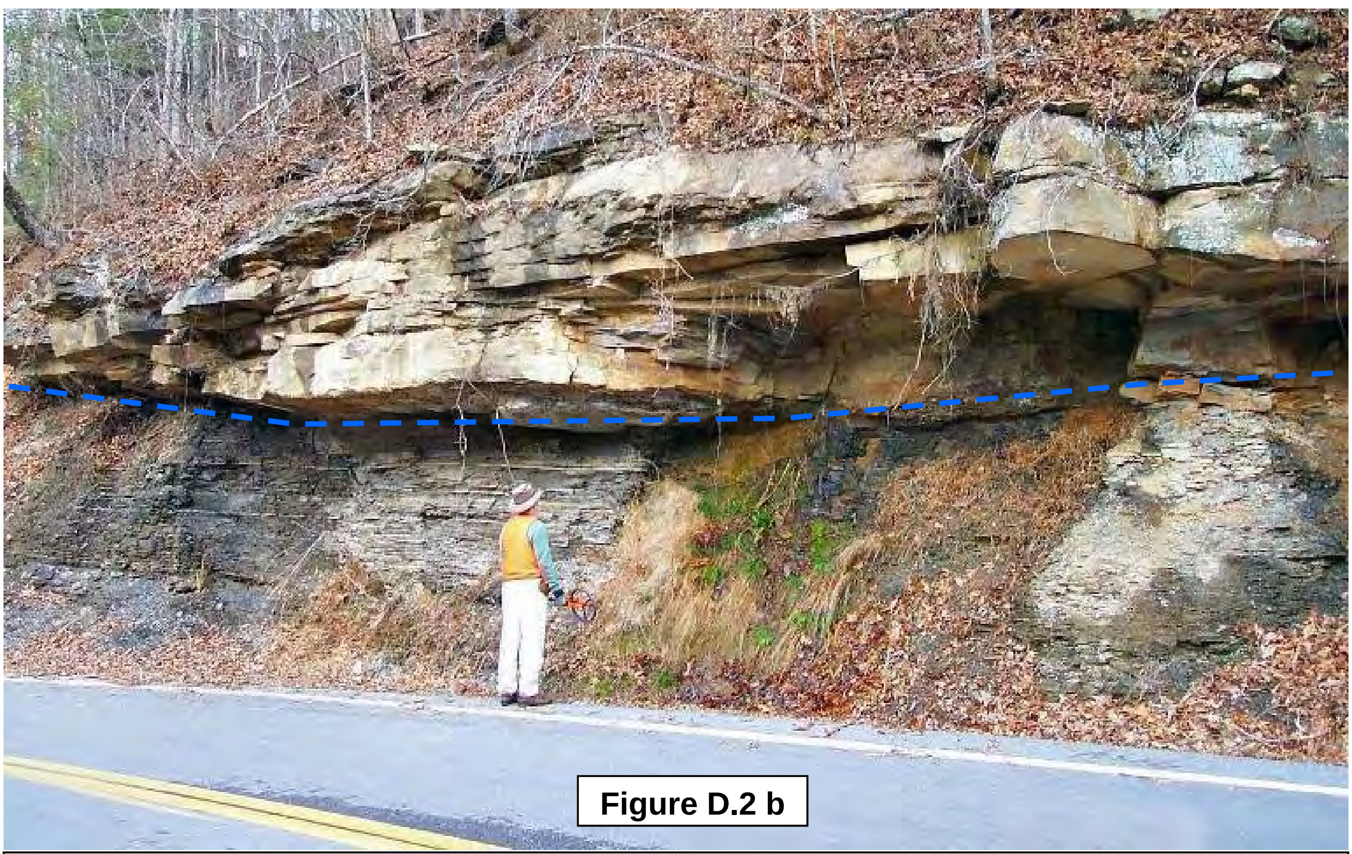


Figure D.2 b

Boundary of the two lithologies is indicated by the dashed line. The upper unit has the potential to fail due to the overhang created by the difference in erosion rates between the two lithologies.
(Anderson County, SR 116, MM 5-50L)

Figure D.3 a

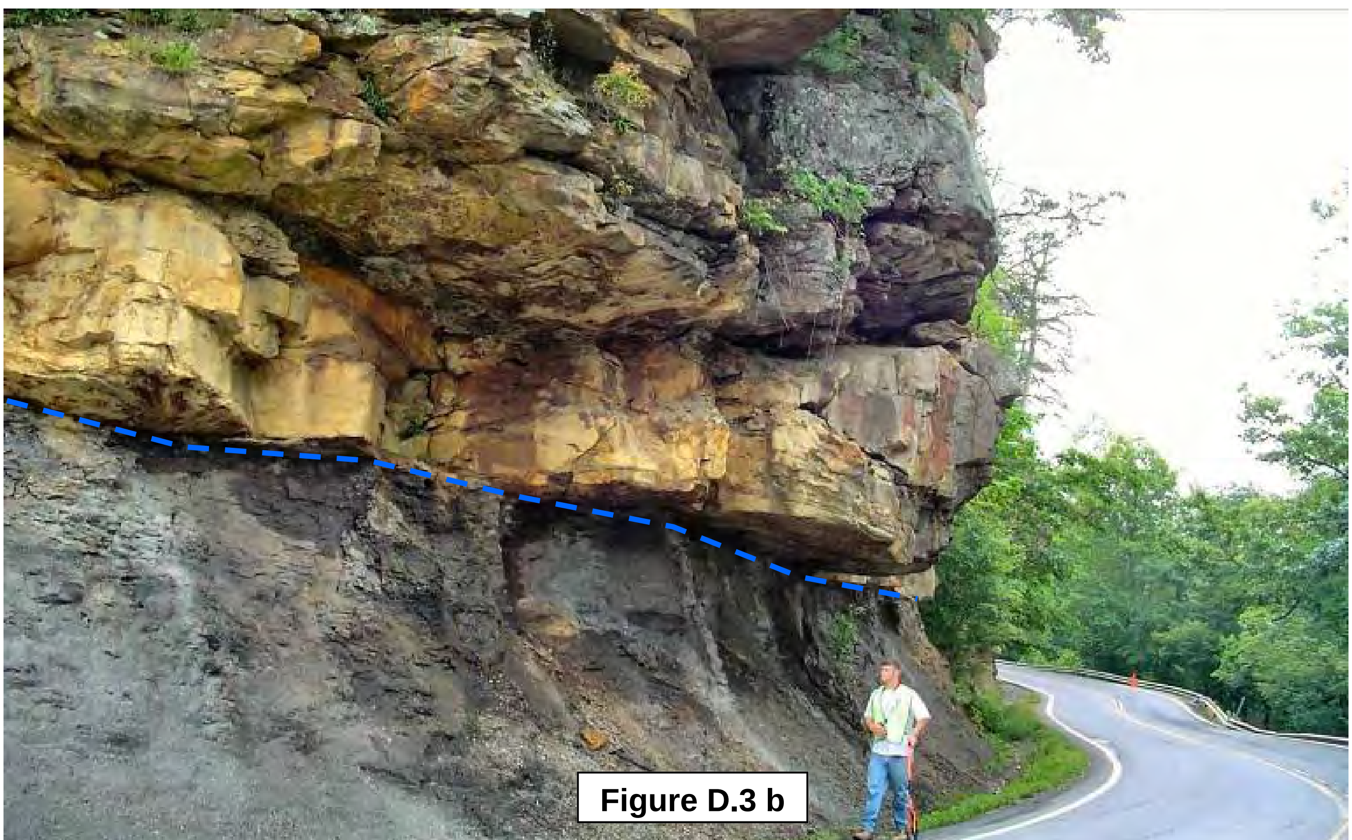


Figure D.3 b

Two lithologies can be seen along the rock cut. An overhang created by the difference in erosion rates between the two units is identified by the dashed line. Note a significant relief along the dashed line. The layers of rocks above the line have potential for topple failure. *(Campbell County, SR 090, MM 2-20L)*

Figure D.4 a

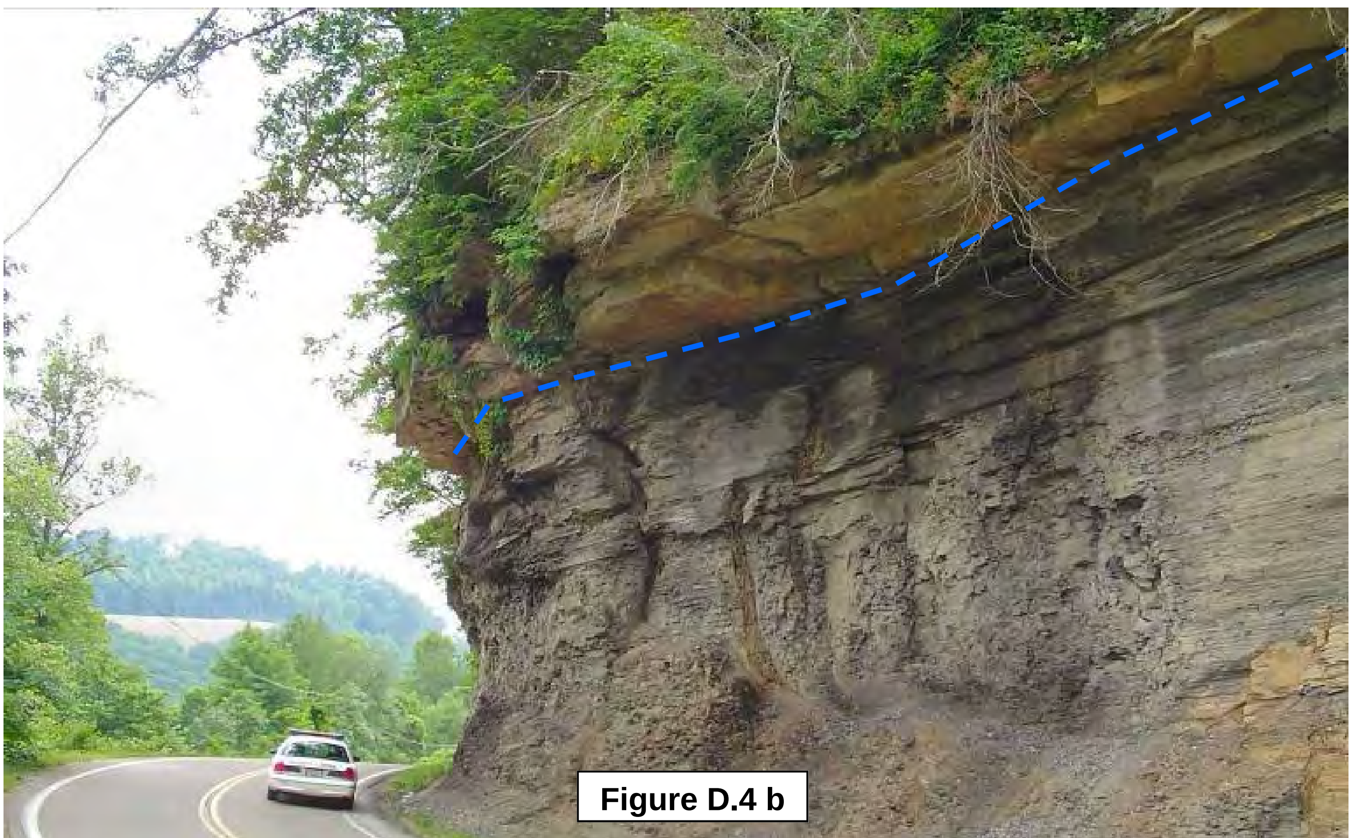


Figure D.4 b

This rockcut shows two lithologies with the lower unit eroding faster than the upper unit. A significant overhang (relief) can be seen along the boundary of the two units (dashed line). The overhanging upper unit is almost directly above the road and has the potential to fail due to the loss of support. Layers of rocks above the dotted line have potential to fail by block release/topple. *(Campbell County, SR 090, MM 3-45L)*

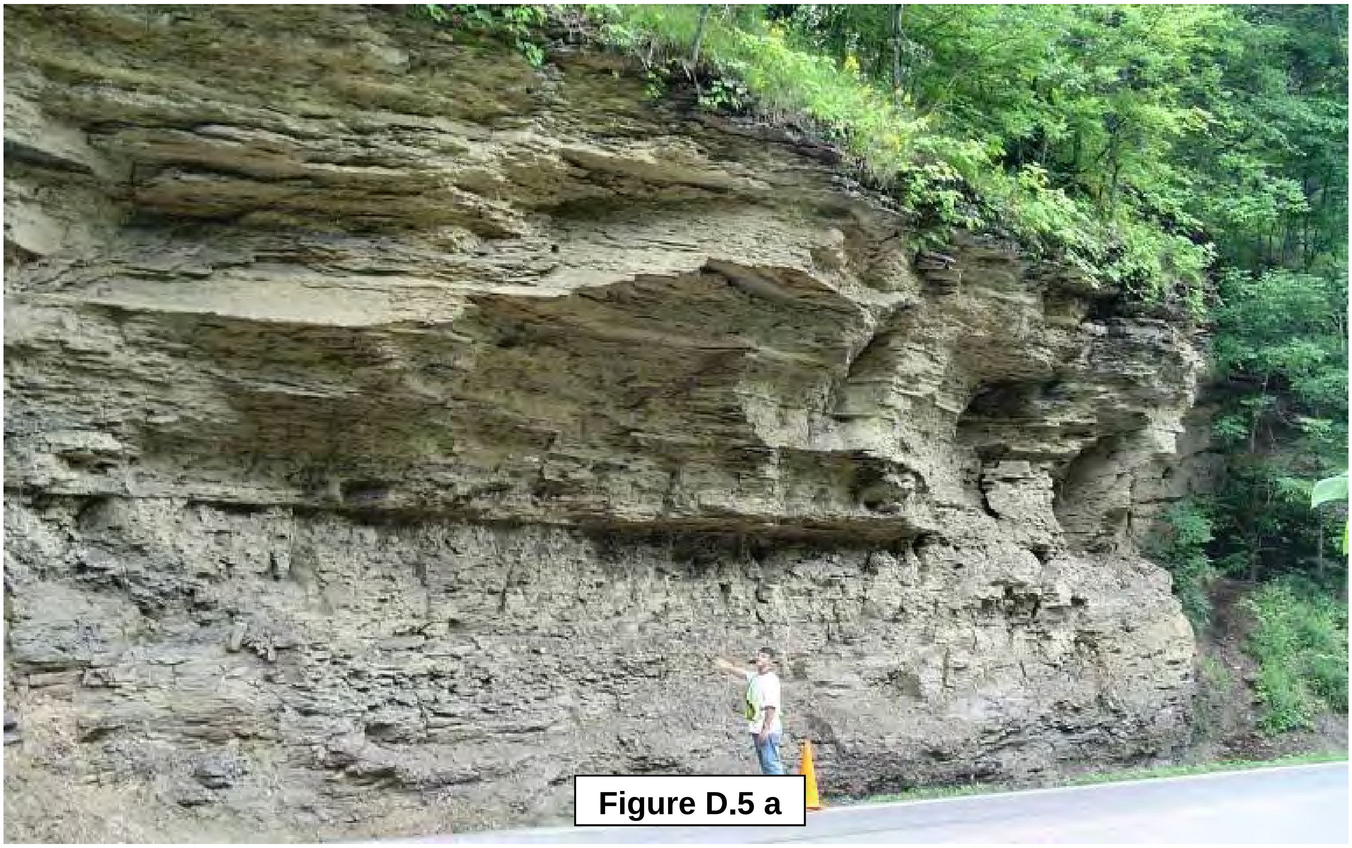


Figure D.5 a

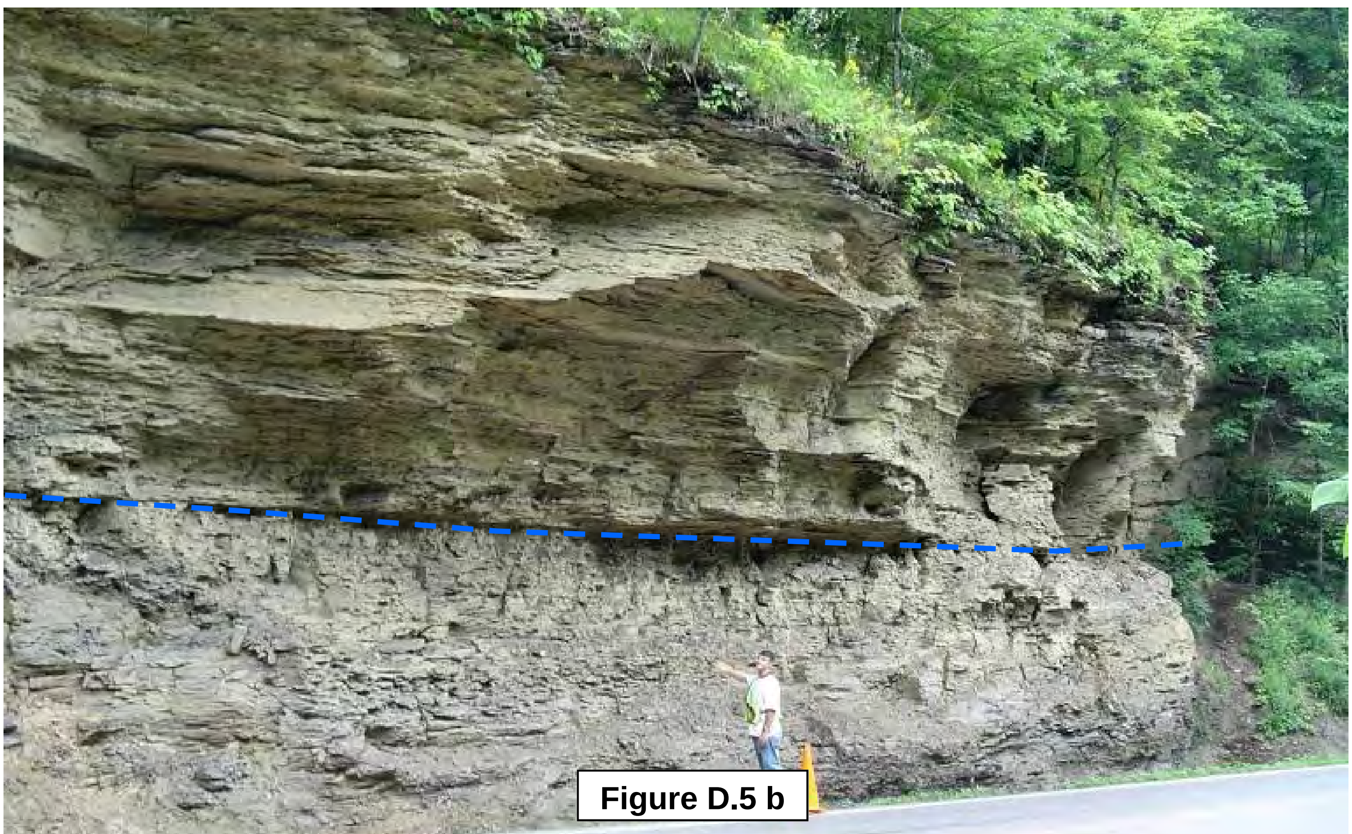


Figure D.5 b

Two lithologies with the different erosion rates can be seen at this rockcut. The unit below the dashed line is eroding faster than the one above, creating an overhang. The overhang along the boundary between the two units leads to the loss of support for the upper unit, and subject it to the potential rockfall. *(Campbell County, SR 090, MM 4-55L)*

Figure D.6 a

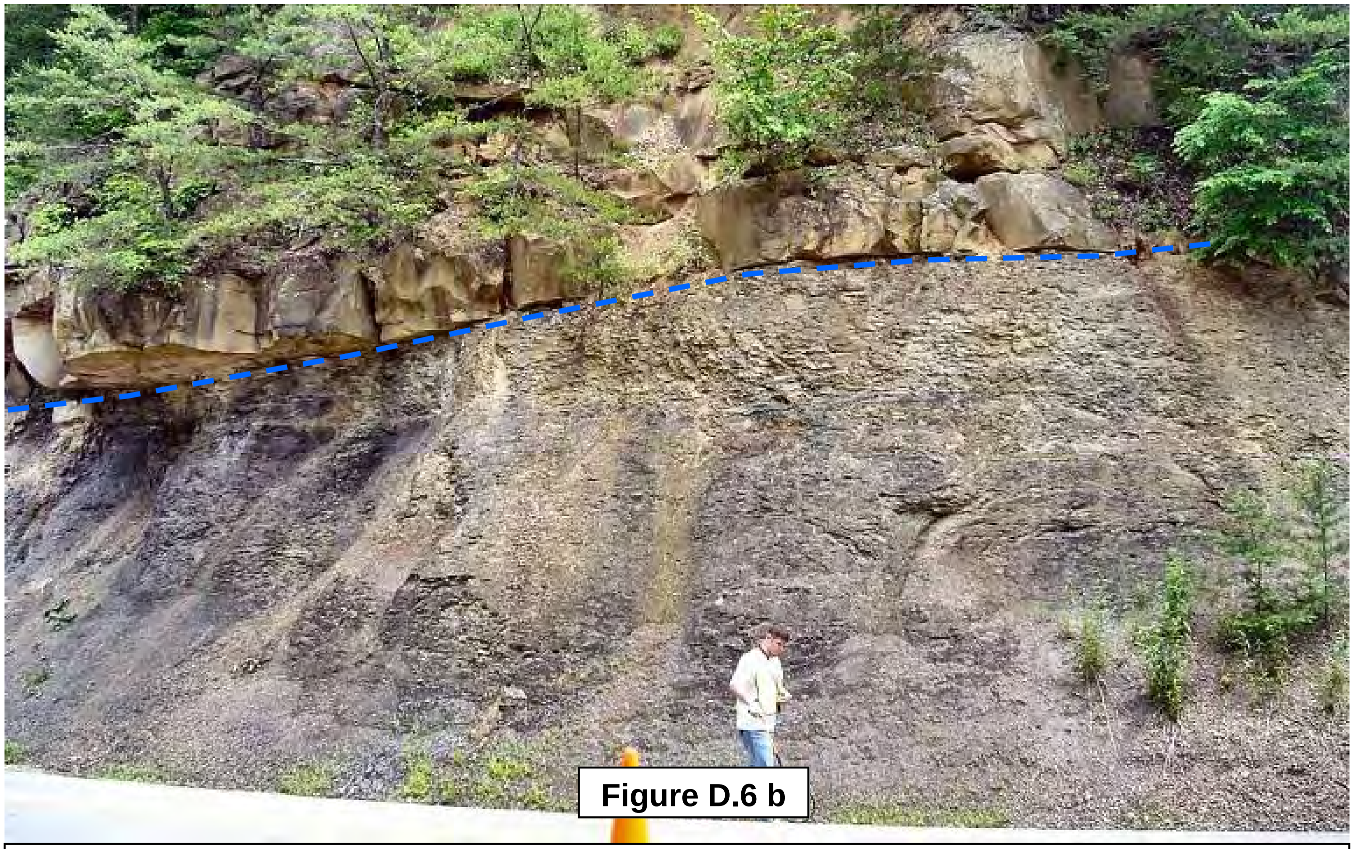


Figure D.6 b

This rock slope consists of two lithologies with the lower unit eroding faster than the upper unit. An overhang created due to the difference in erosion rates can be seen on the left section of the slope. The overhanging layer has the potential to fail by rotating out as a direct result of the difference in erosion rates.
(Campbell County, SR 090, MM 2-05L)

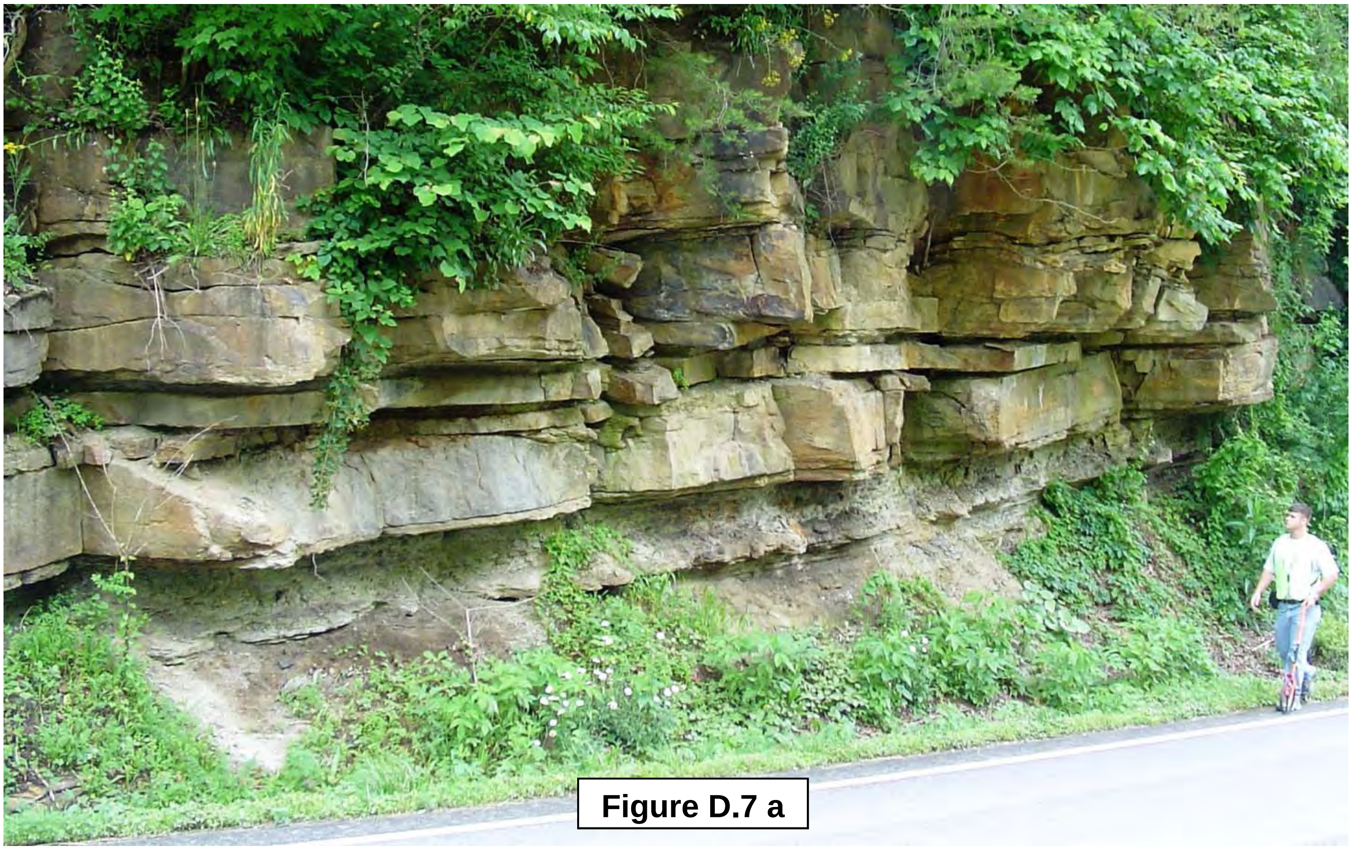


Figure D.7 a

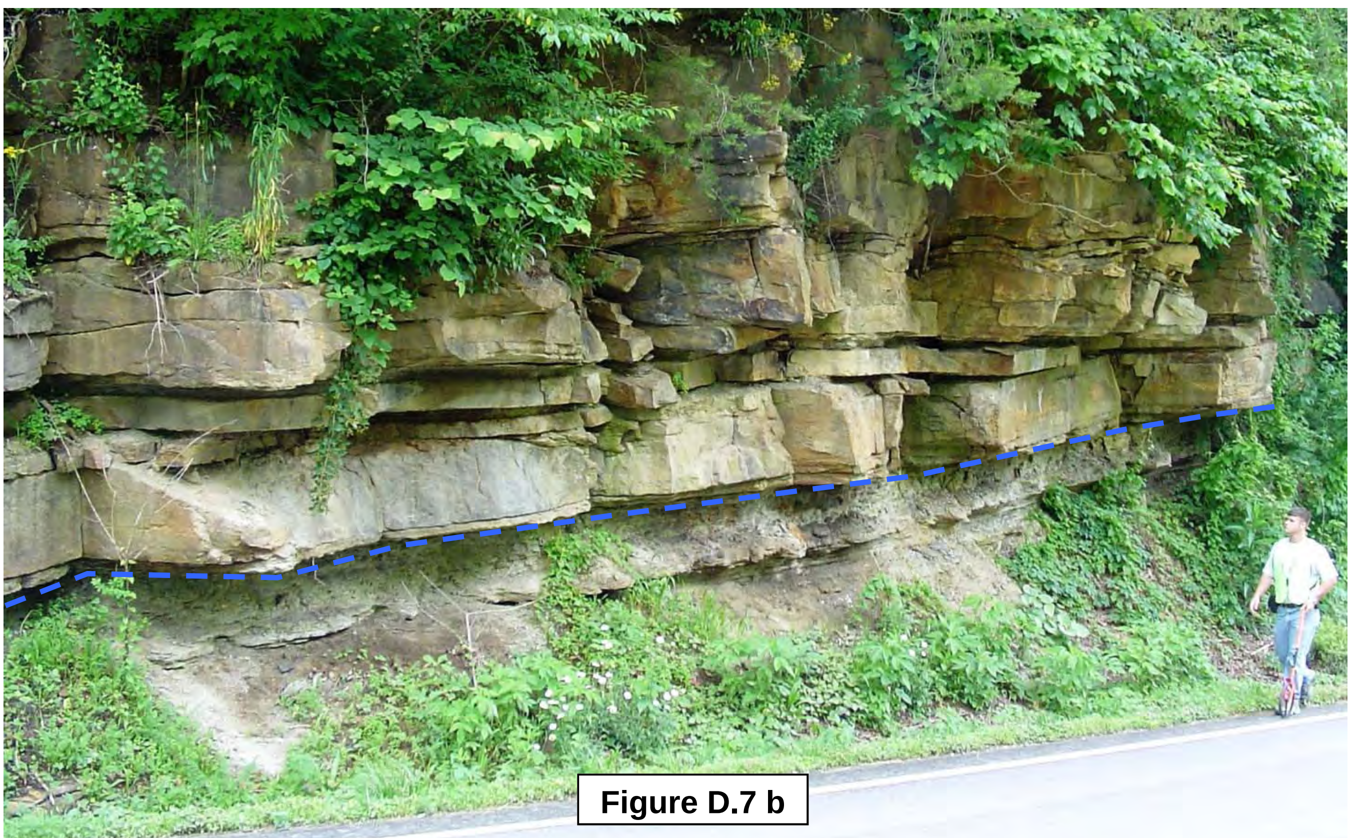


Figure D.7 b

Two lithologies with different erosion rates can be seen at this rockcut. The unit below the dashed line is eroding faster than the unit above the dashed line, creating an overhang between the two units. The more resistant unit has the potential for block release/topple failure as its support from the faster eroding unit decreases.
(Campbell County, SR 009, MM 18-40)

Figure D.8 a

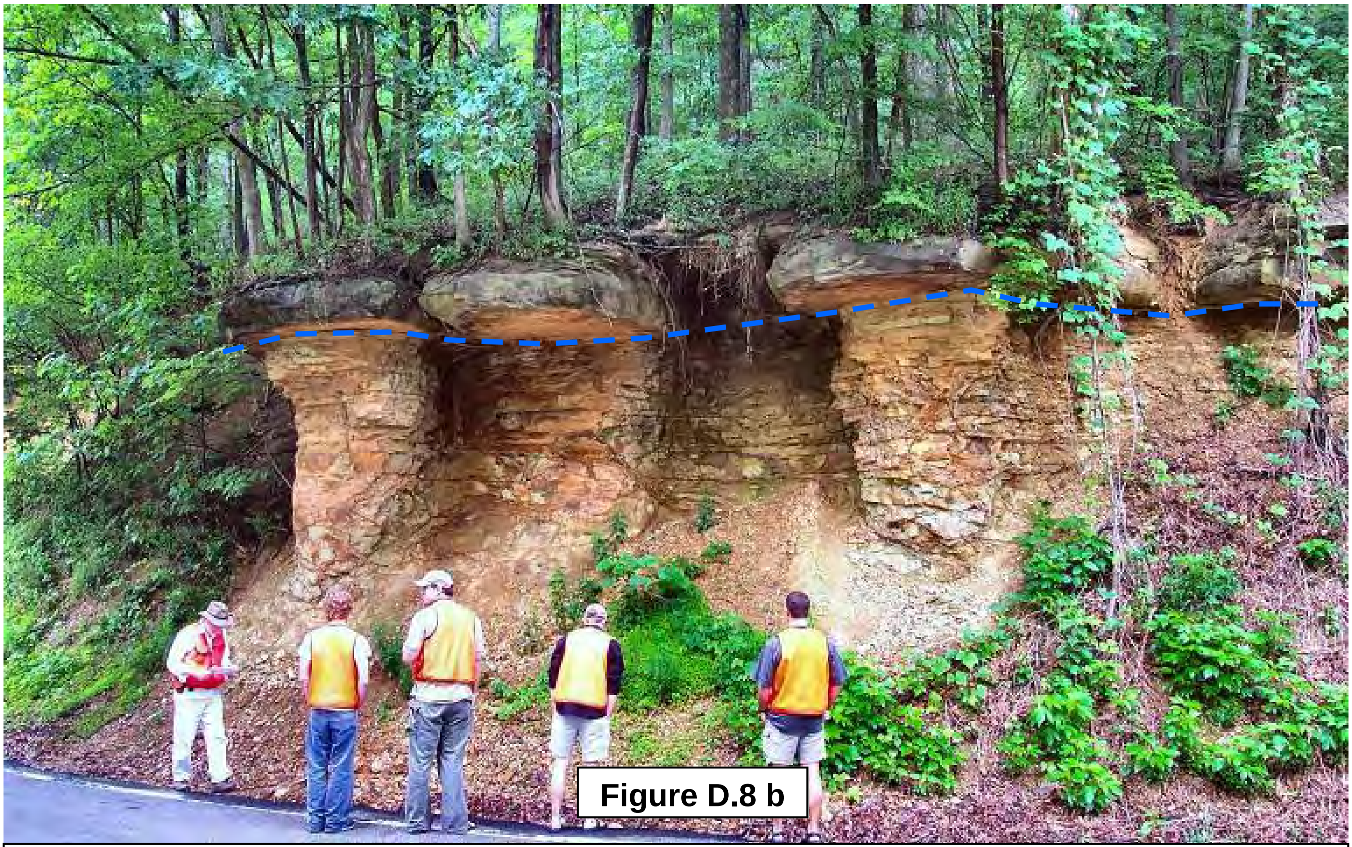


Figure D.8 b

An overhang created by the difference in erosion rates between two lithologies can be seen on the rock slope. As the unit below the dashed line continues to erode, the unit above the dashed line has the potential to fail due to the lack of support.
(Morgan County, SR 116, MM 2-90L)

Figure D.9 a

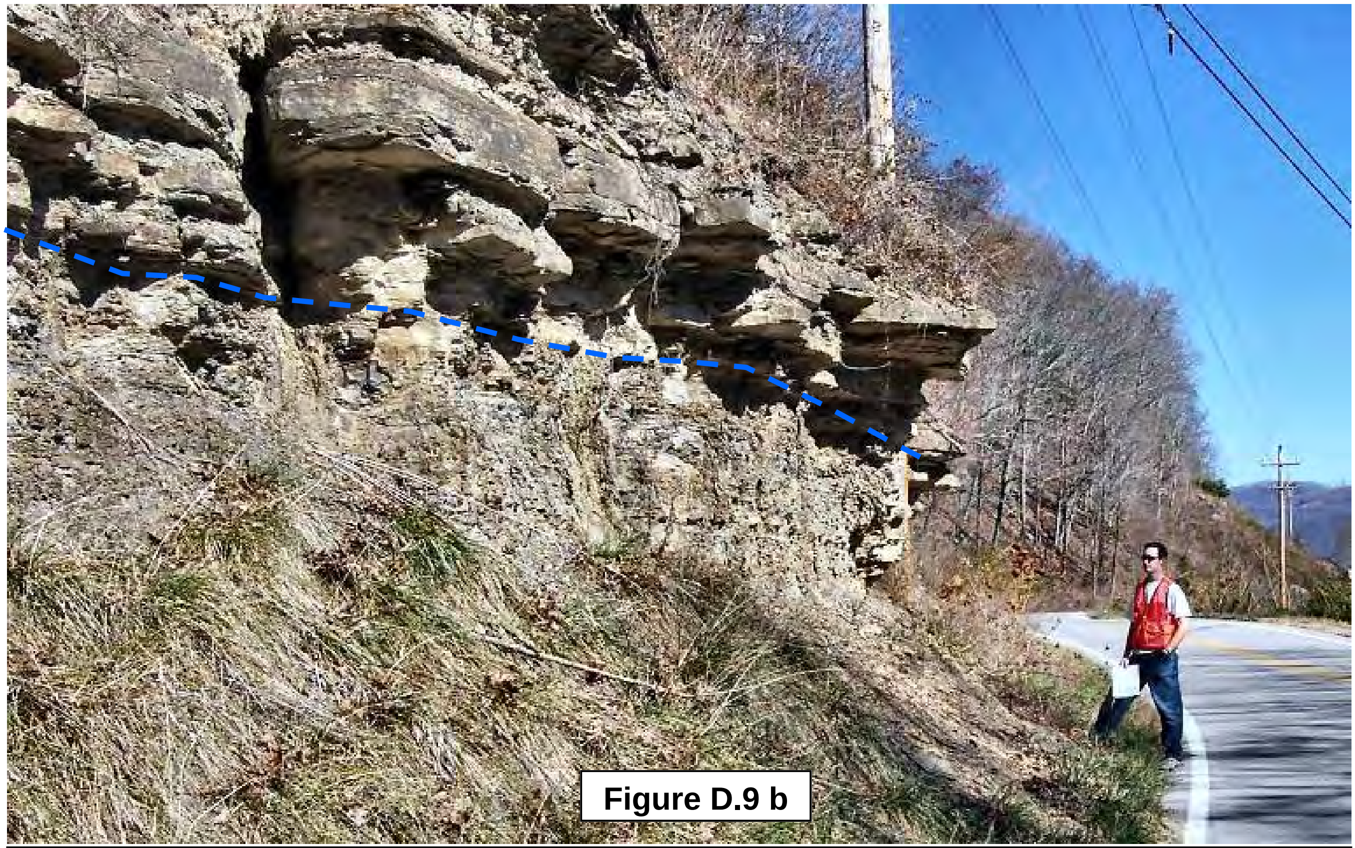


Figure D.9 b

This rock slope consists of two lithologies with the lower unit eroding faster than the upper unit. The difference in erosion rates produces an overhang along the boundary between the two units (dashed line). The overhanging unit has the potential to fail by rotating out due to the loss of support.
(Anderson County, SR 116, MM 3-60L)

Figure D.10 a

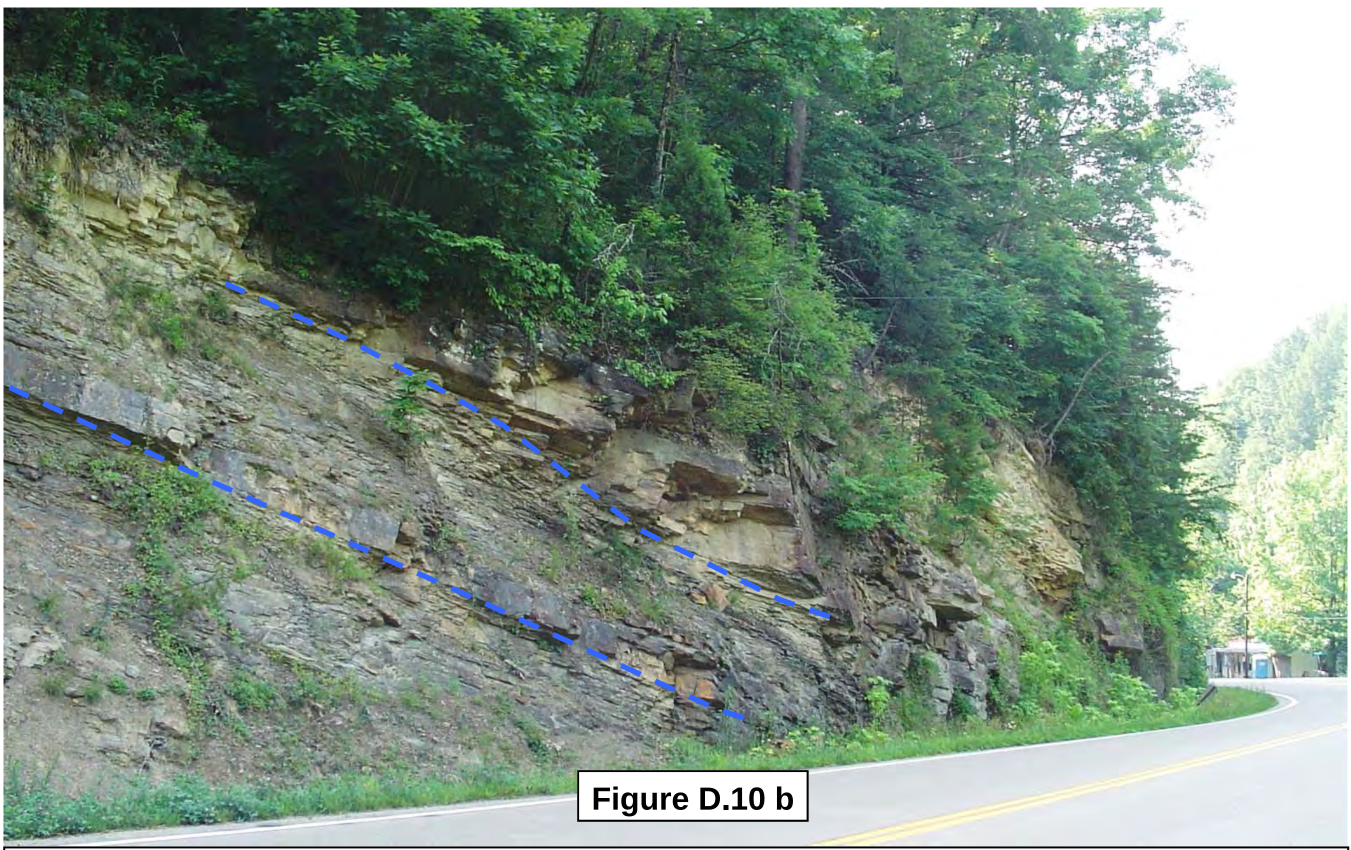


Figure D.10 b

This rockcut shows repeating layers of two lithologies with one unit eroding faster than the other. Overhangs created by the difference in erosion rates can be seen along the dashed lines. As differential erosion progresses, the more resistant layers will become unsupported and gain potential to fail.
(Hawkins County, SR 031, MM 4-60R)

Chapter 1.5:

Raveling Failure

Raveling is the shedding of rock blocks due to erosion and non-specific failure mechanisms. Raveling may be caused by general erosion, by root jacking, frost wedging and also by blasting damage. This category is used to describe rock failures that cannot be classified as planar, wedge, topple or differential weathering. Block sizes are generally smaller with raveling than with other failure mechanisms.

Following pictures contain rock faces that exhibit characteristics for potential raveling failure. Such characteristics are:

- Weathering results in gradual decomposition of rock mass
- Progressive loosening and shedding of blocks by no distinct sliding or rotational mechanism

Figure E.1 a

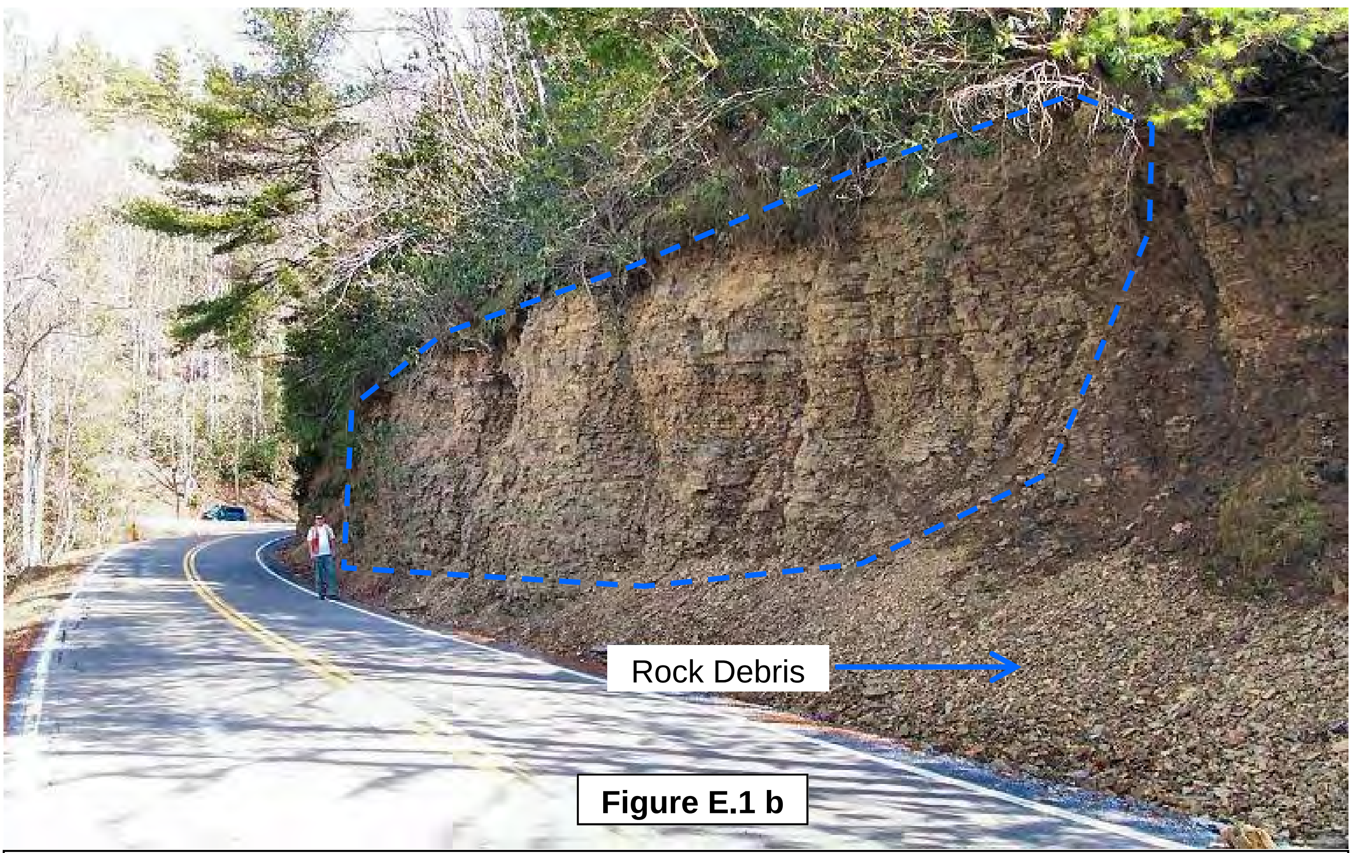
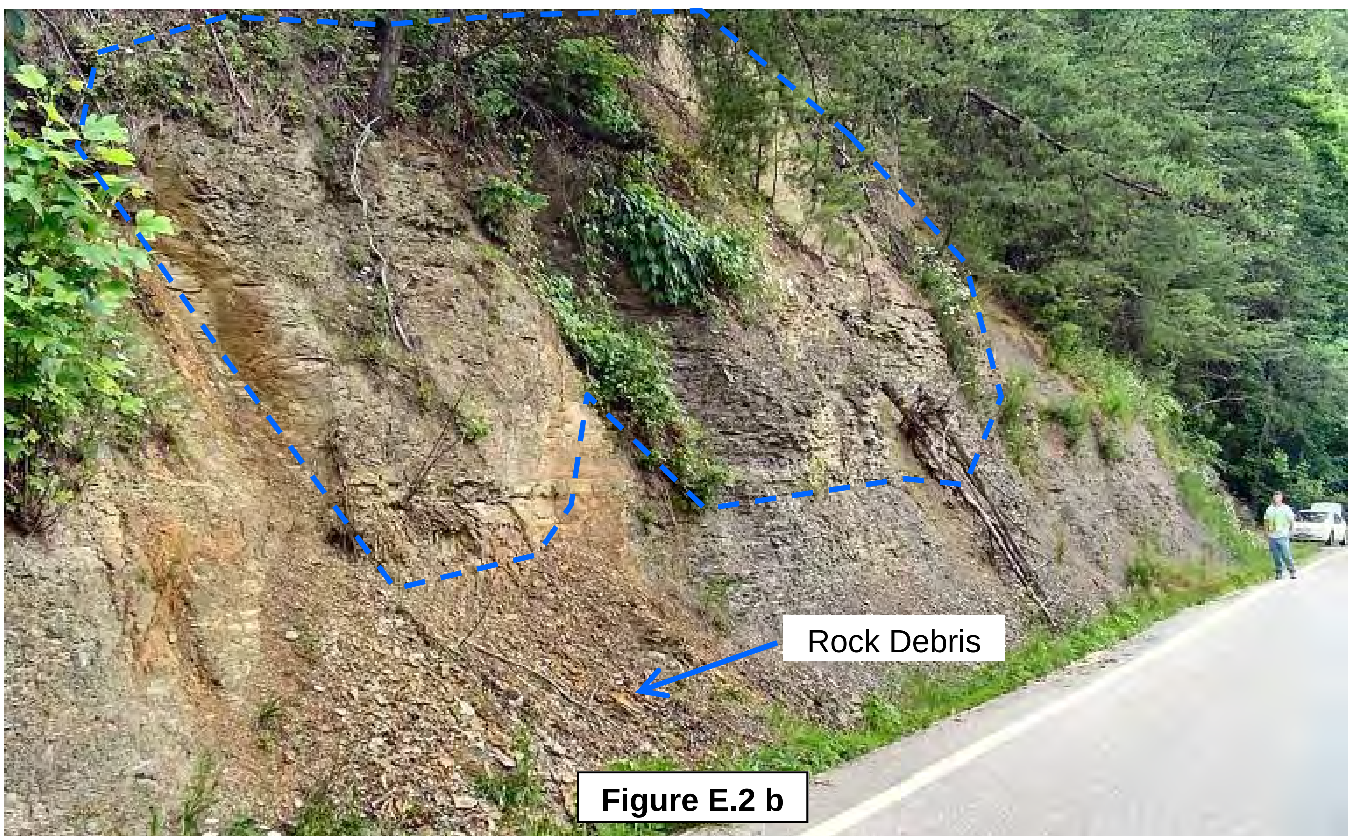


Figure E.1 b

Rock face shows highly weathered surface and evidence of gradual shedding of loose small rock blocks (note accumulation of rock debris bottom right of slope).
(Carter County, SR 091, MM 19-30R)



Lower part of the rock cut exhibits shedding of small rock blocks (note accumulation). The rock face (dashed line) shows potential for further loosening of small blocks due to weathering.
(Campbell County, SR 297, MM 1-00R)

Figure E.3 a

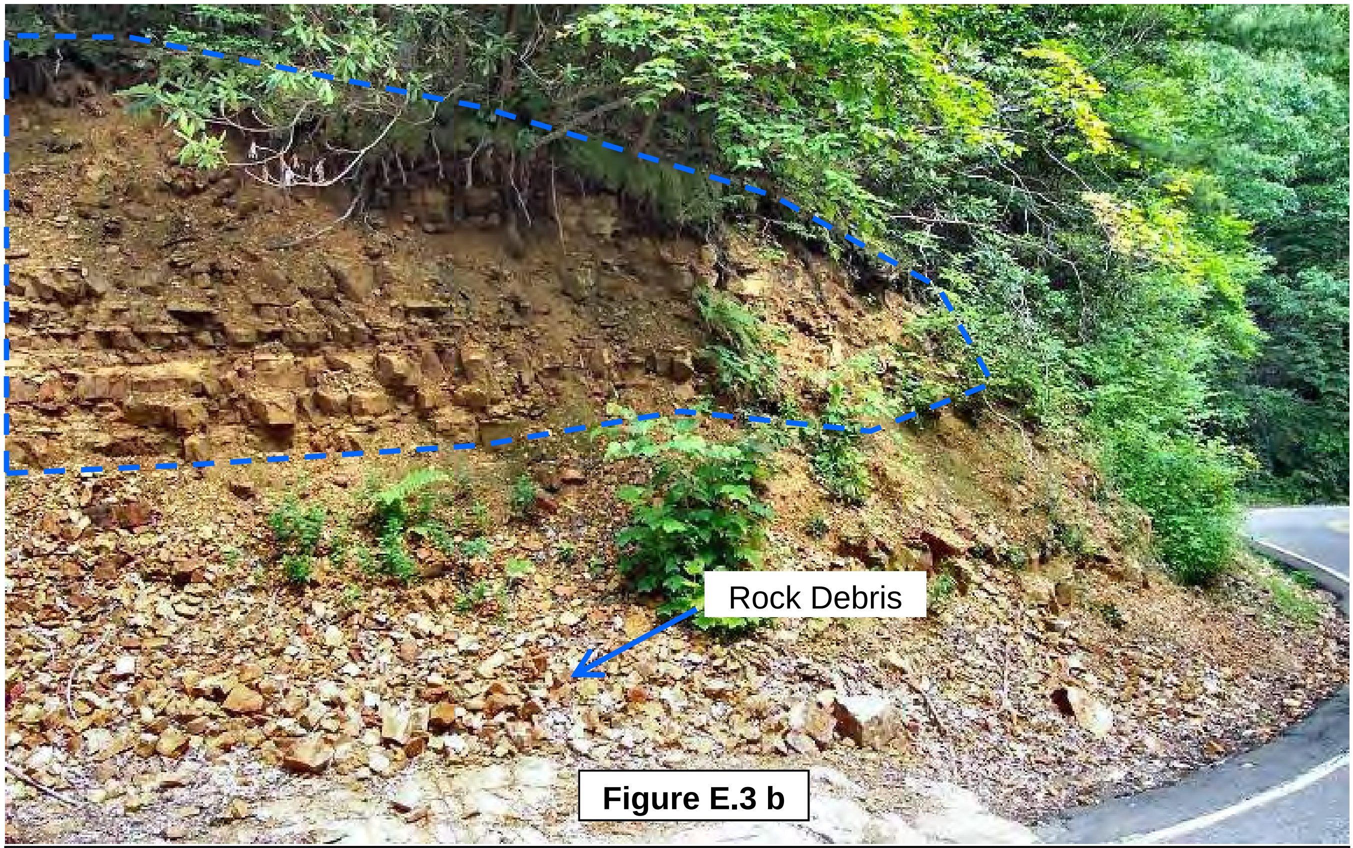


Figure E.3 b

Accumulated rock blocks ranging in size from gravel to 1ft can be seen at the bottom of the rock cut. Further loosening of these blocks from the weathered rock face, outlined in dashed line, is possible. However, most of the rock debris are captured in the ditch, resulting in B or C slope. *(Carter County, SR 091, MM 19-70R)*

Figure E.4 a

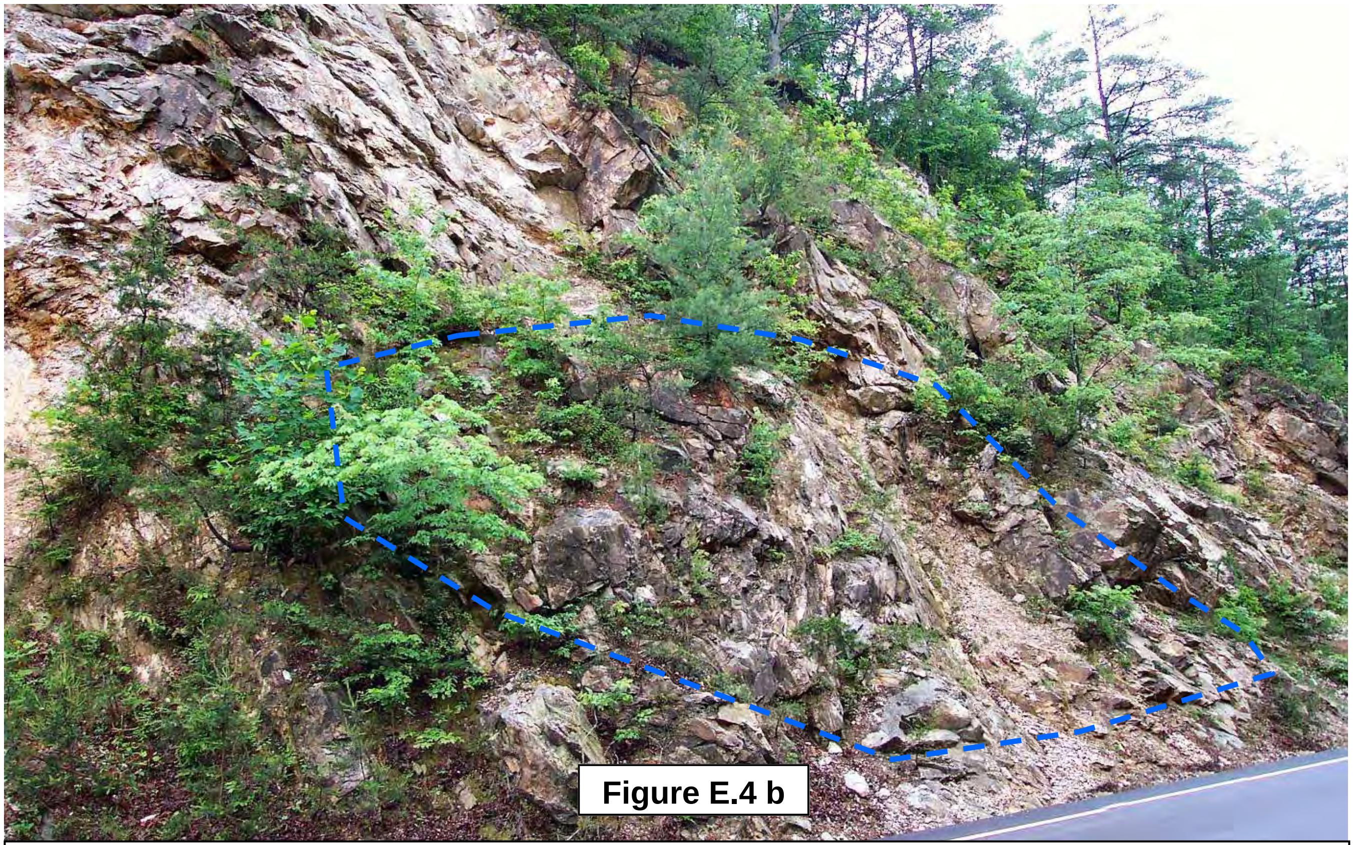


Figure E.4 b

Above rock face is highly fractured and consists of rock blocks of various sizes (gravel size to 1ft+) which have potential to fail and reach the road. No obvious and distinct mechanism of failure can be identified for the rock blocks and therefore, this slope is rated as raveling failure.
(Roane County, SR 001, MM 00-70R)

Figure E.5 a

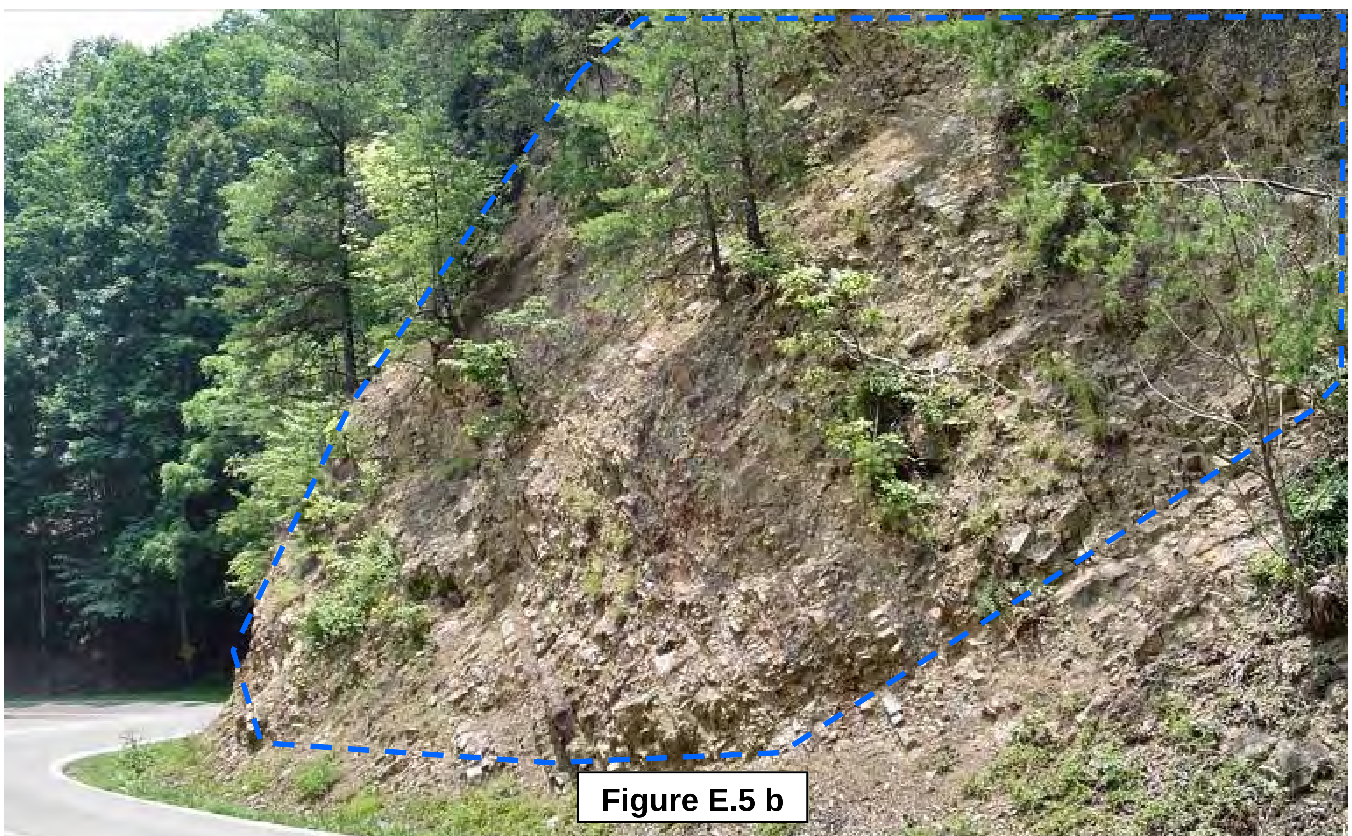


Figure E.5 b

The thinly layered rock mass dips away from the road, suggesting potential toppling. However, no toppling is observe. The rock face is highly fractured and likely to shed small blocks, i.e., ravel.
(Hawkins County, SR 066, MM 20-20L)

Figure E.6 a

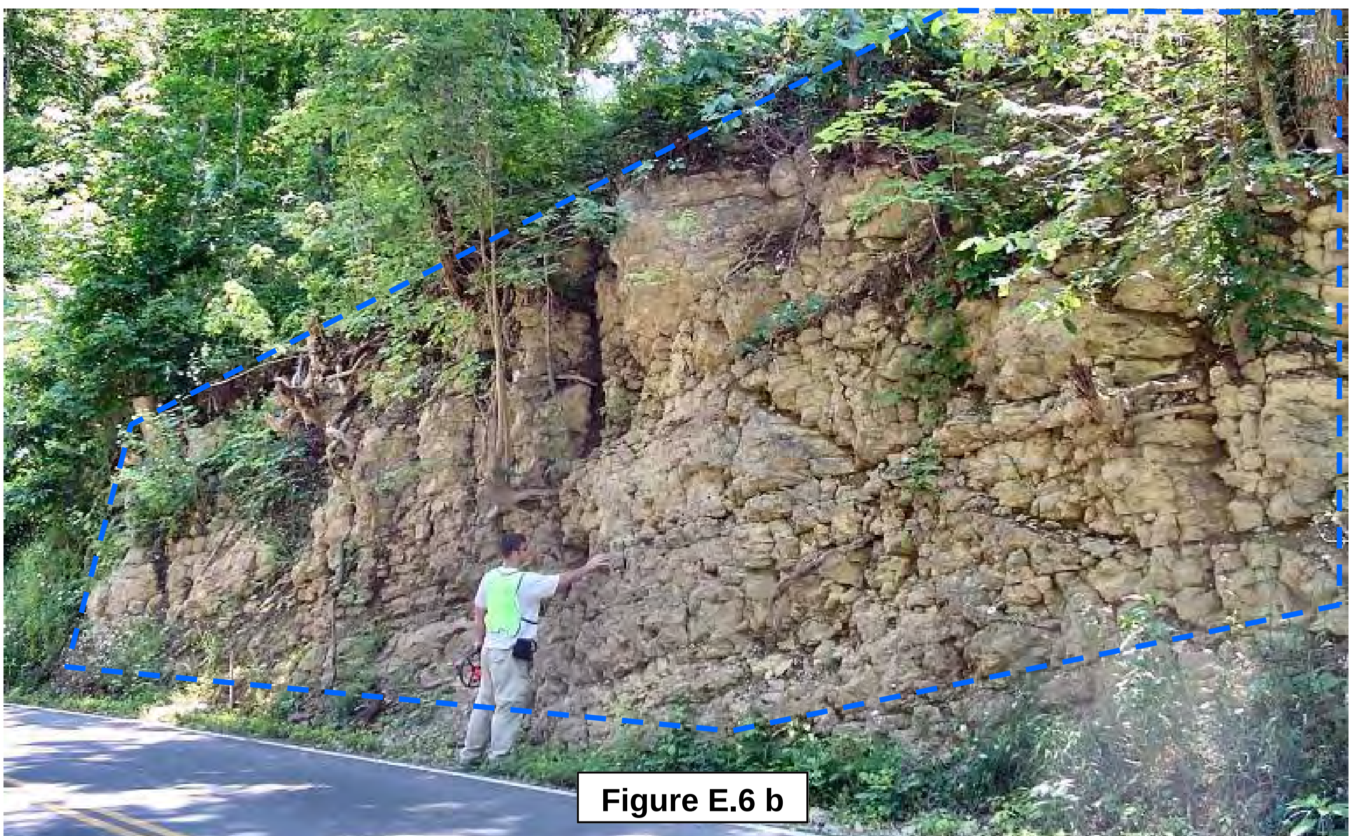


Figure E.6 b

This rock face is highly weathered and highly fractured, and has the potential to shed rock blocks onto the road.
(Hancock County, SR 033, MM 8-10)

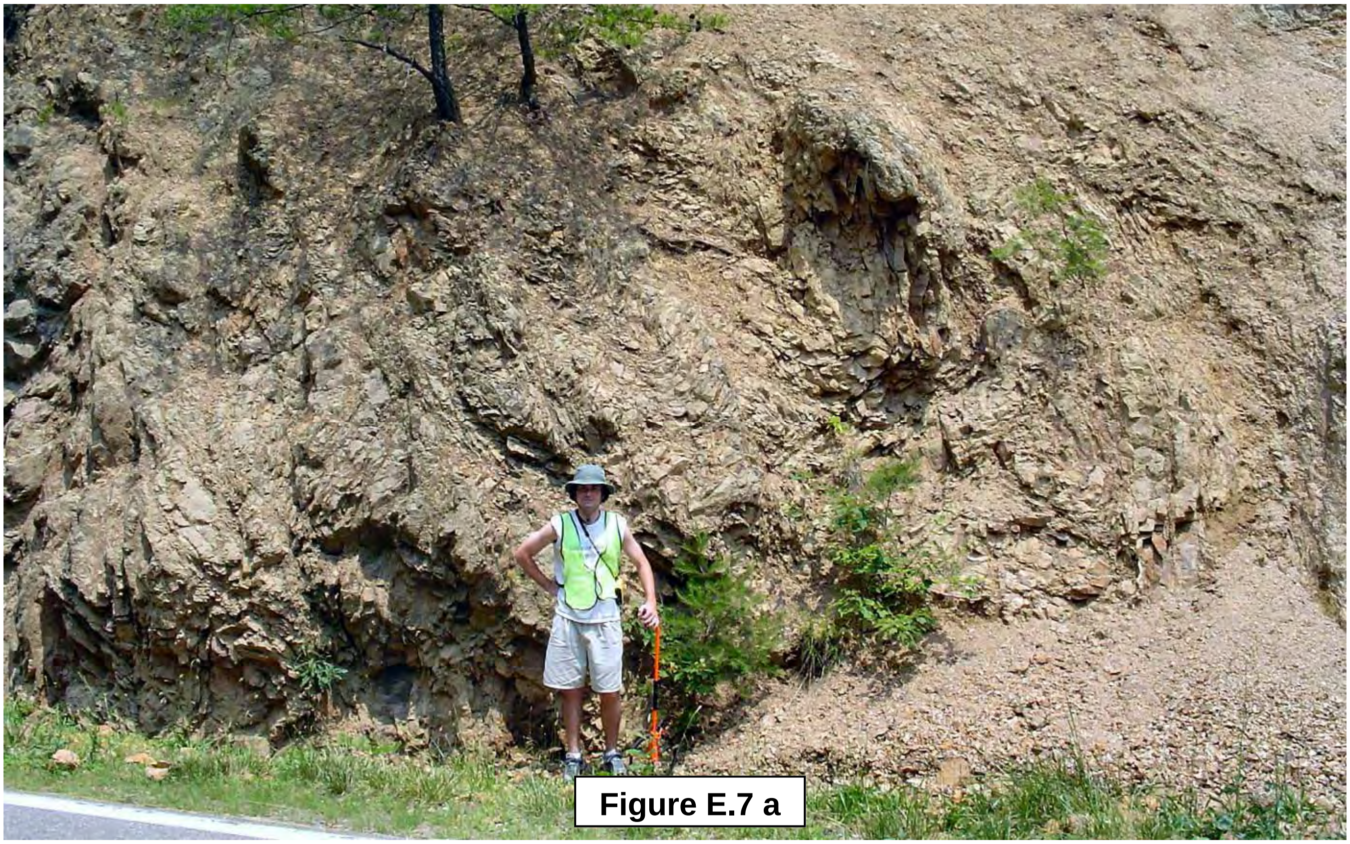


Figure E.7 a

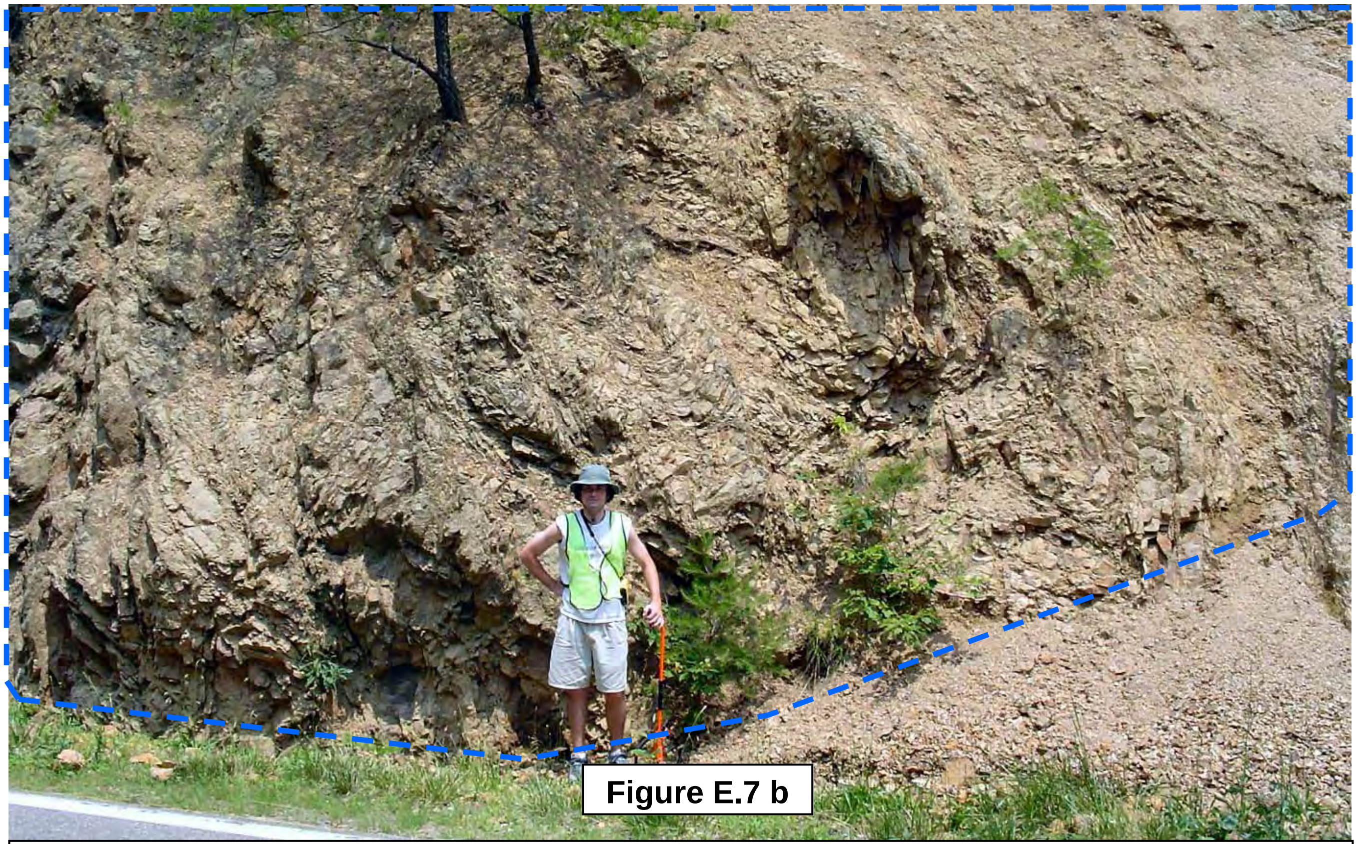


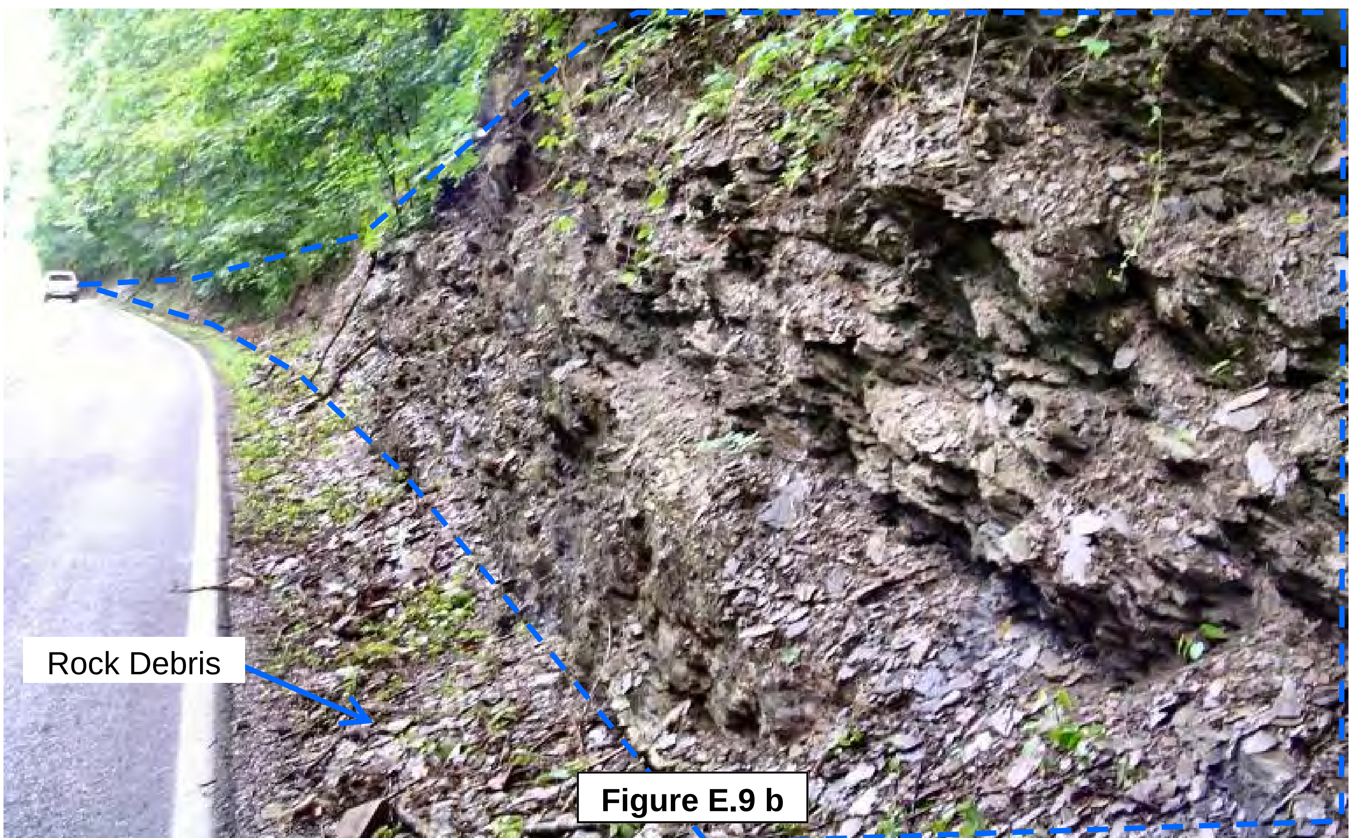
Figure E.7 b

A highly fractured and weathered rock mass is exposed at this cut. This slope is likely to shed rock blocks onto the road without any distinct failure mechanism.
(Hawkins County, SR 066, MM 20-70R)

Figure E.8 a

Figure E.8 b

An accumulation of small rock blocks can be seen in the catchment ditch. The fractured and weathered slope surface has the potential to shed further rock blocks onto the road.
(Hawkins County, SR 066, MM 25-45R)



The rock slope is shedding flakes and small slabs of rock due to weathering. Raveled debris can be observed at the bottom of the slope.
(Sullivan County, SR 093, MM 00-10R)

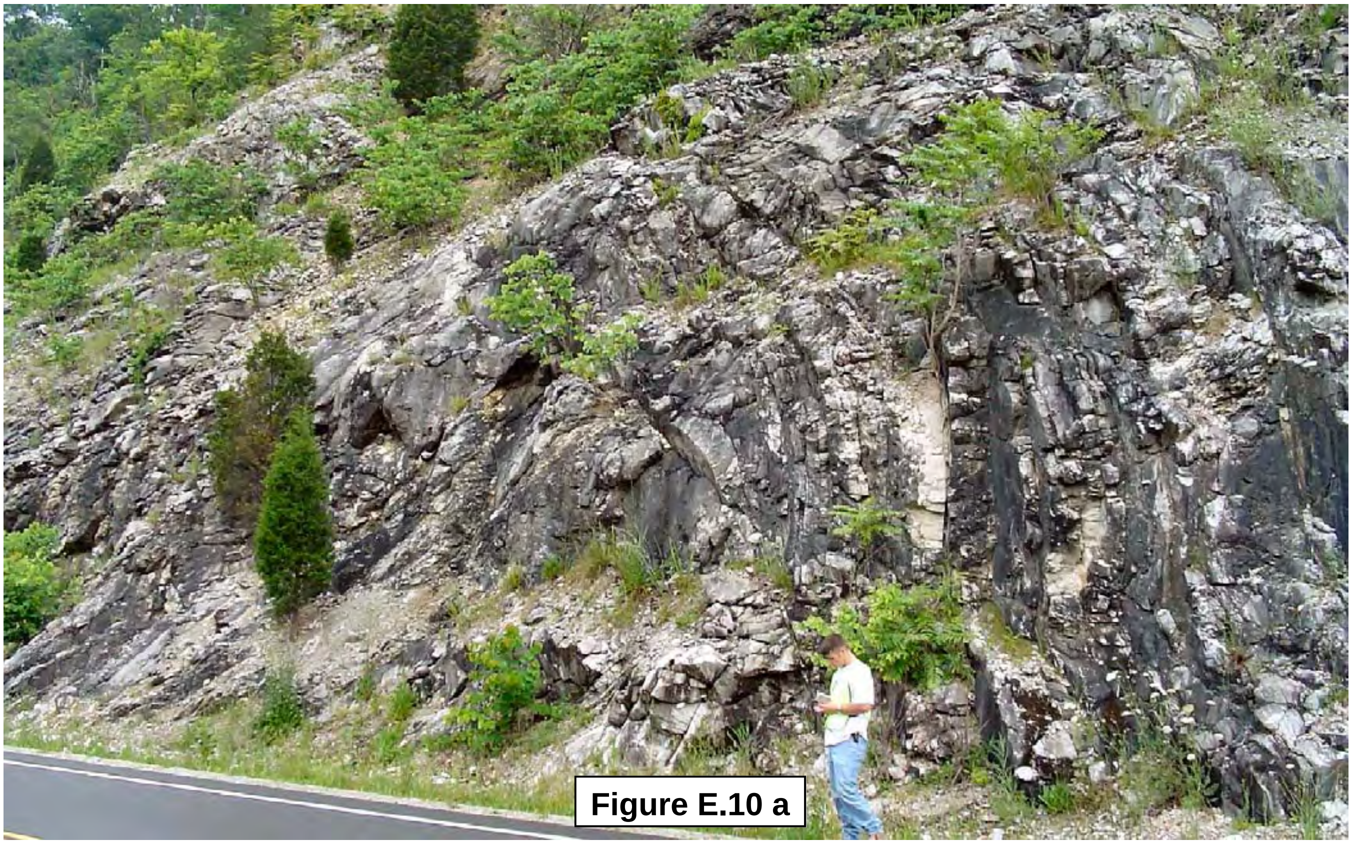


Figure E.10 a

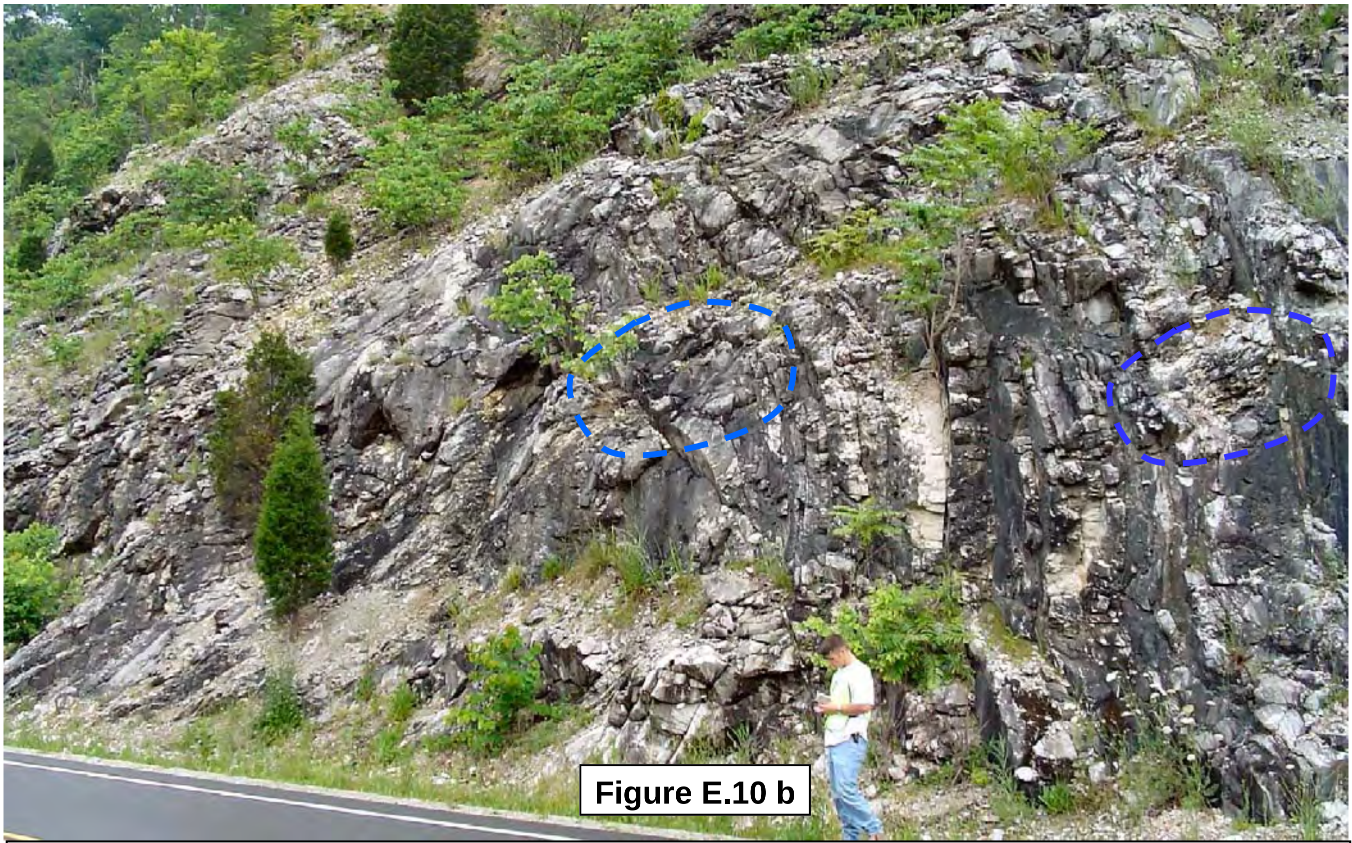


Figure E.10 b

Blasting damage (e.g., inside dashed lines) can be observed on the above rock cut. As a result, the slope face is highly fractured in specific areas and shows potential to shed loose rock blocks onto the road.
(Campbell County, SR 116, MM 4-60)

Chapter 2:

Geologic Failure Mode Abundance Assessment

Chapter 2 contains example pictures of rock faces with potential failure modes and estimated abundance of each identified mode

Each identified failure mode is indicated with dashed lines and labeled accordingly using the following abbreviations:

P = Planar
W = Wedge
T = Topple
DW = Differential Weathering
R = Raveling

Abundance is visually estimated based on areas of the rockcut. For the purpose of the training manual, length of the rockcut captured in figures are assumed to be the total length of the cut and the abundance percentage was estimated accordingly. However, the field abundance ratings may differ from the ones shown in this chapter because the slope length represented in each picture may only be a portion of a longer rockcut. When assigning an abundance in the field, the entire rockcut should be considered.

Figure 2.1 a

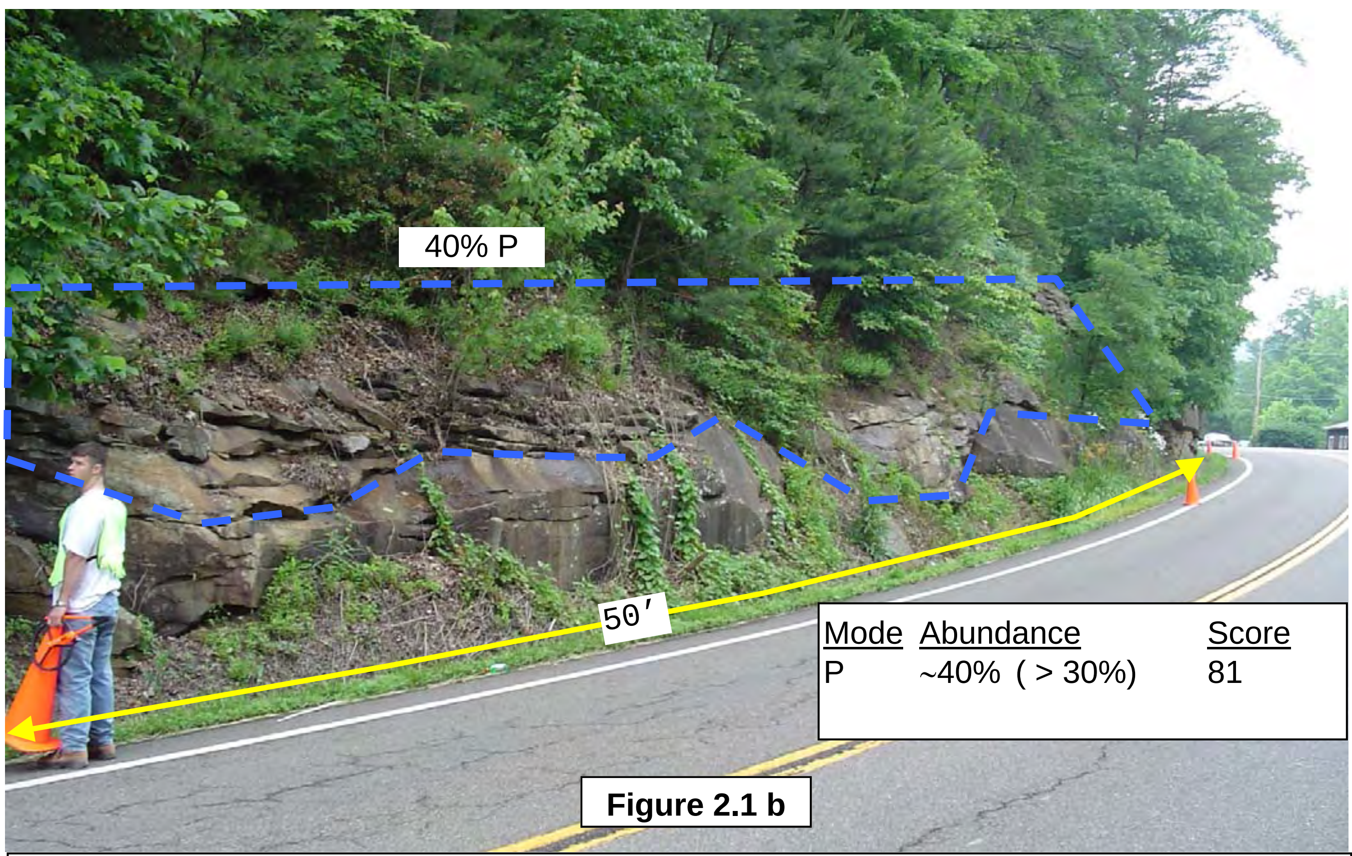


Figure 2.1 b

This rock cut exhibits characteristics of planar failure mode. The portion of the rock slope identified by the dashed lines have the potential to fail by sliding on a single plane and reach the road. For the length of cut shown, approximately 40 % of the rock face is deemed to have the potential for planar failure.
(Campbell County, SR 009, MM 8-30)

Figure 2.2 a

Mode	Abundance	Score
W	~50% (> 30%)	81

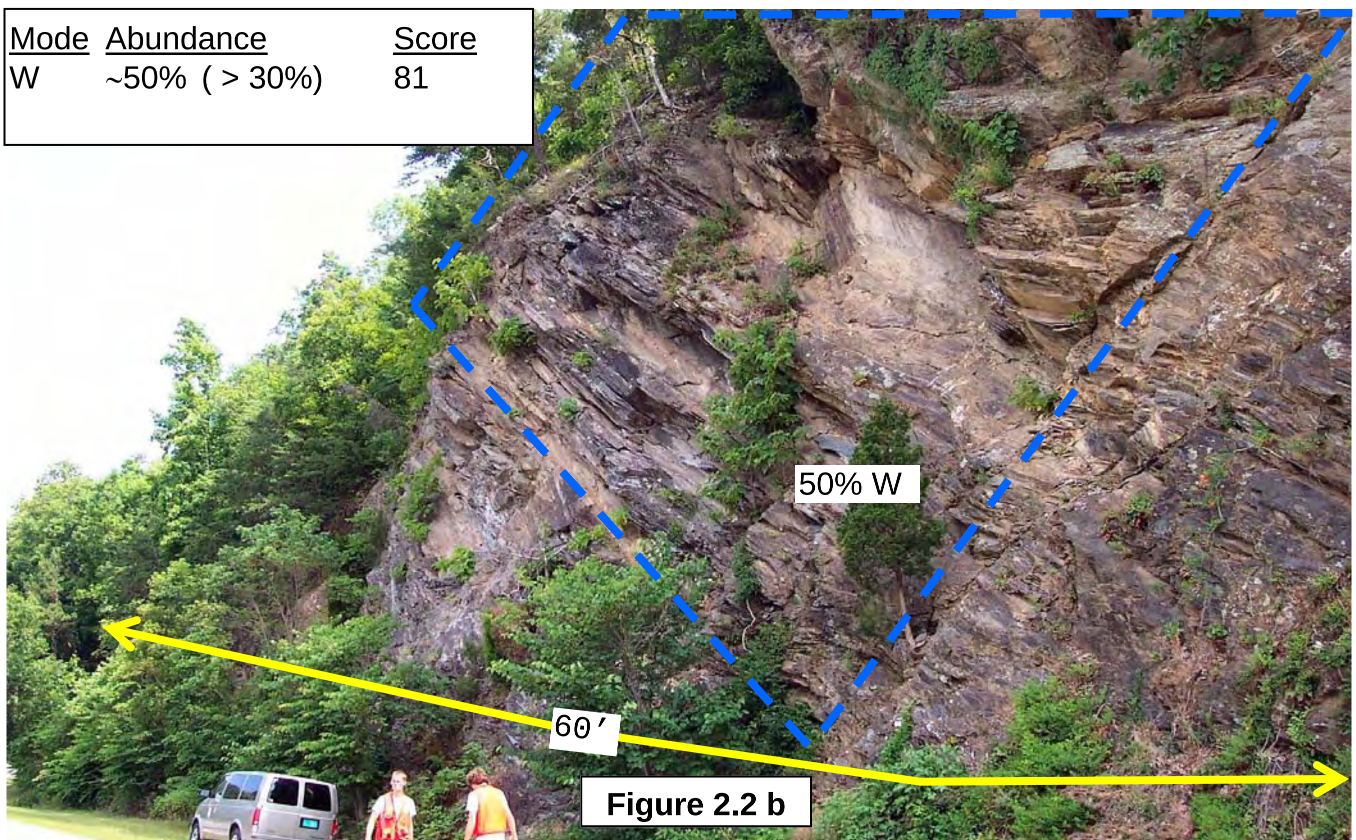


Figure 2.2 b

Wedge failure potential occurs for this cut. The rest of the cut is stable. For the length of cut shown, approximately 50 % of the rock face is deemed to have the potential for wedge sliding. The wedge abundance score at this rockcut is 81 since the estimated abundance exceeds 30%.
(Blount County, SR 115, MM 12-20)

Figure 2.3 a

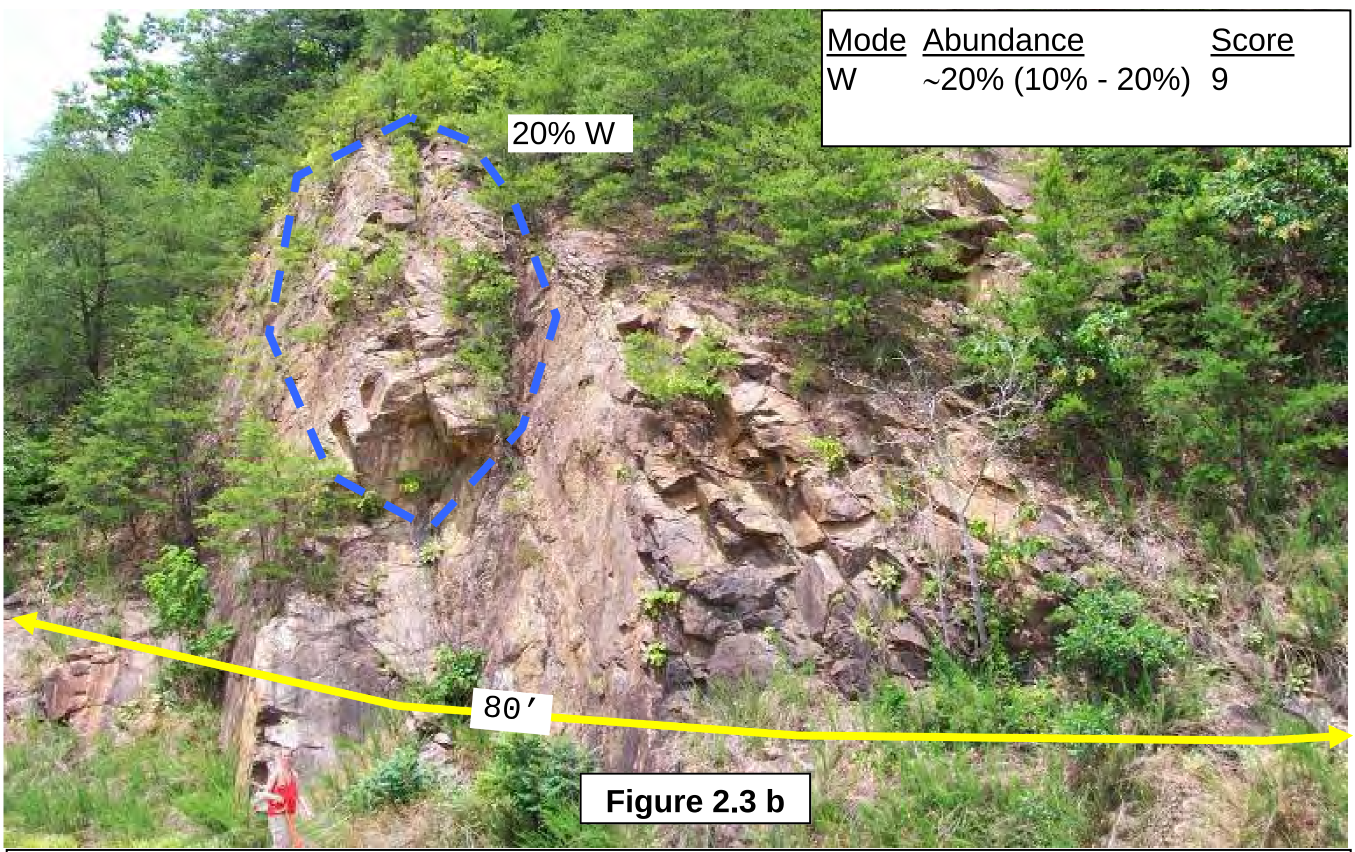


Figure 2.3 b

This rockcut has limited potential for wedge failure. For the length of cut shown, 20% of the slope is estimated to have the potential to fail by wedge slide. This rockcut should be rated as wedge failure with the abundance that falls in between 10% and 20%. This abundance range corresponds to the abundance score of 9.
(Blount County, SR 115, MM 15-00R)

Figure 2.4 a

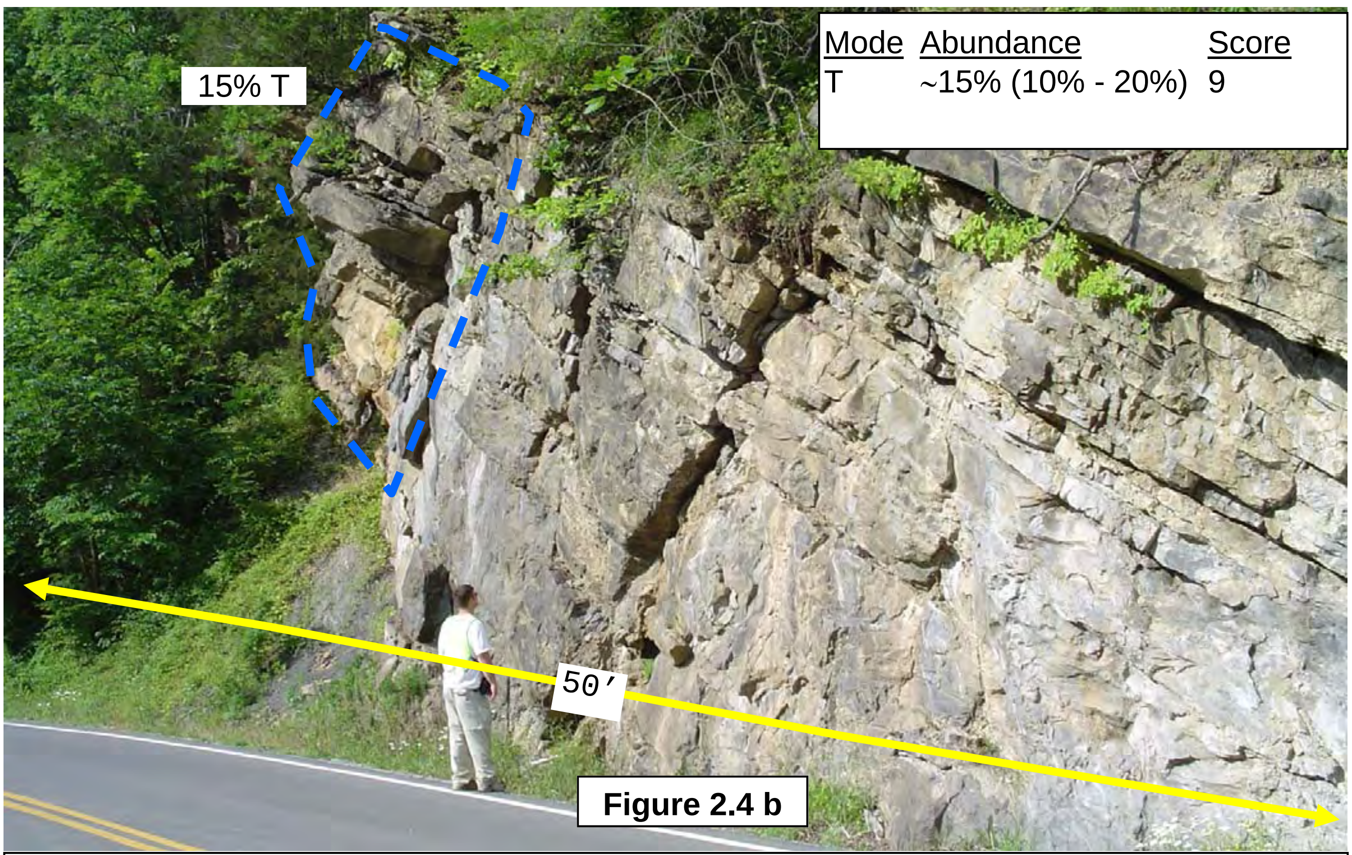


Figure 2.4 b

The nose on this rockcut shows significant local relief and exhibits characteristics for toppling failure. Assuming that what is shown here is the total length of the rockcut, roughly 15% of the slope (dashed line) has the potential for topple failure. A topple abundance between 10% - 20% corresponds to the abundance score of 9.

(Hancock County, SR 033, MM 16-70)

Figure 2.5 a

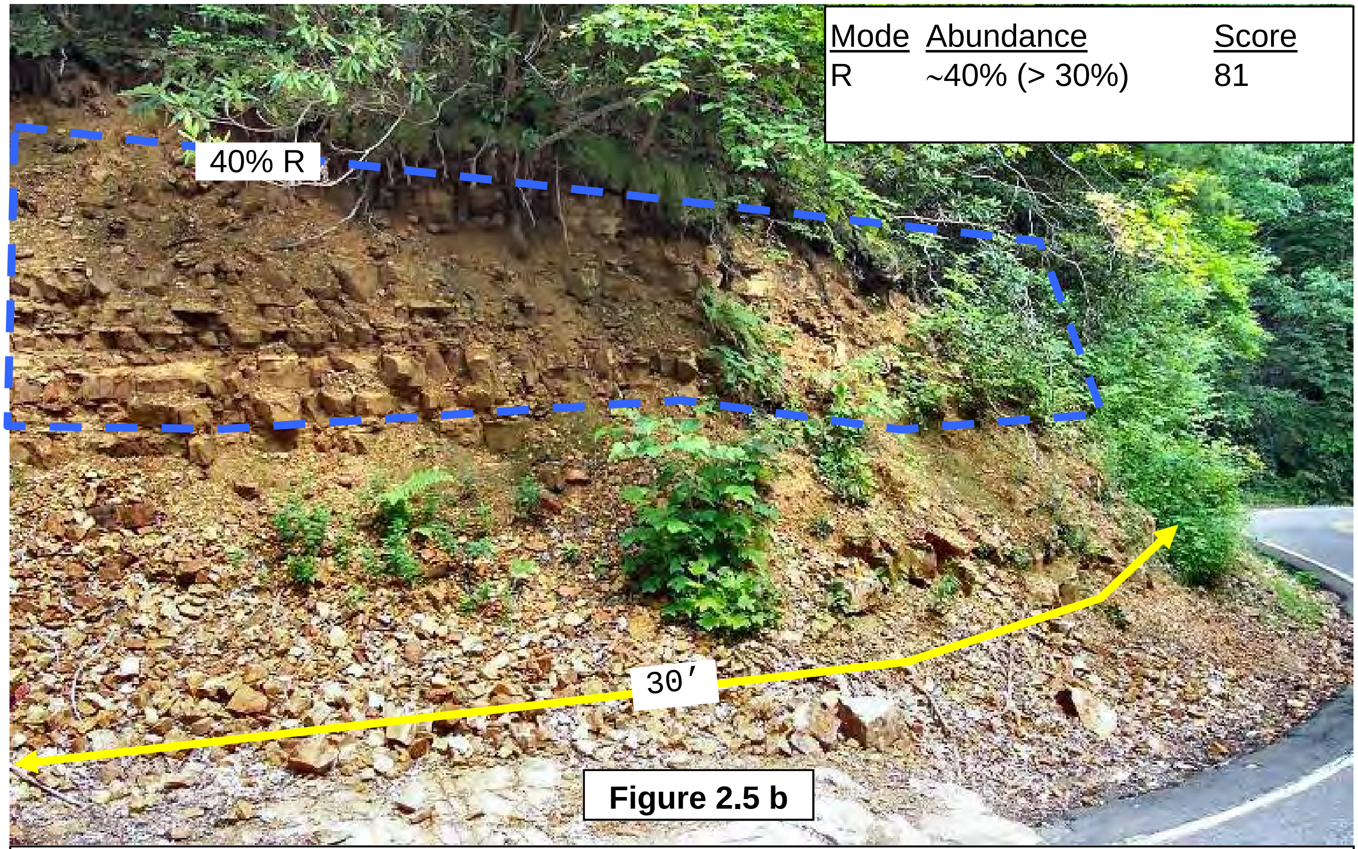


Figure 2.5 b

Potential raveling failure mode is present at this rockcut. For the length of cut shown, 40% of the cut has the potential to fail by raveling. This rockcut should be rated as having the potential for raveling failure with an abundance that is greater than 30% which correlates to the abundance score of 81.
(Carter County, SR 091, MM 19-70)

Figure 2.6 a

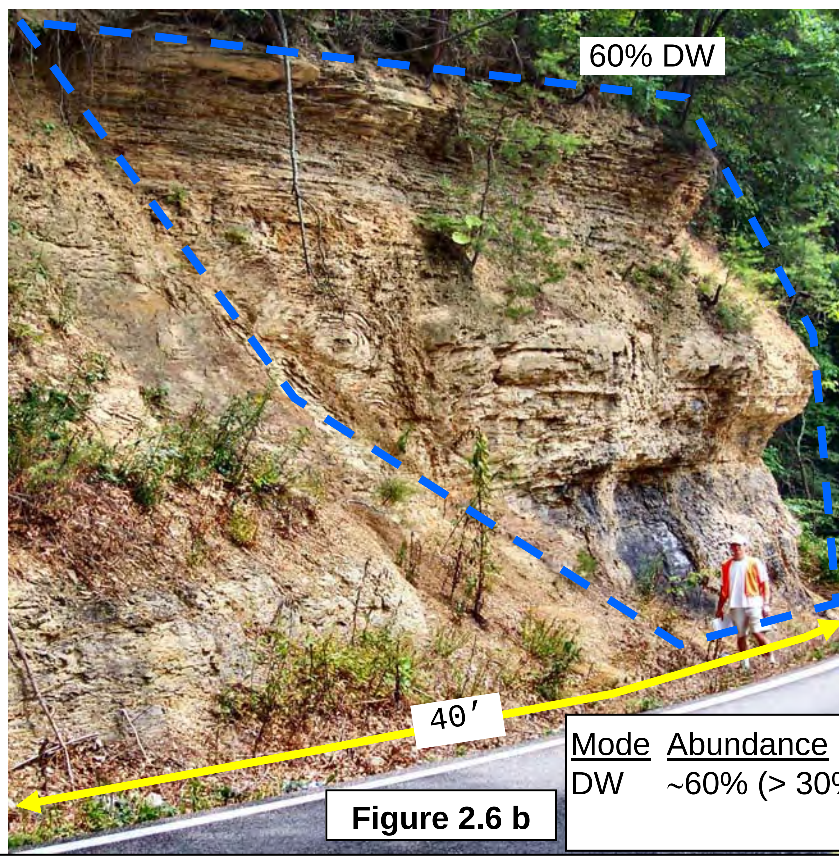


Figure 2.6 b

Mode	Abundance	Score
DW	~60% (> 30%)	81

Much of this rock cut shows non-uniform weathering behavior, creating local relief. For the length of cut shown, approximately 60 % of the rock face is subject to potential differential weathering failure. The areas on the left of the slope is judged to be stable.
(Anderson County, SR 116, MM 9-50)

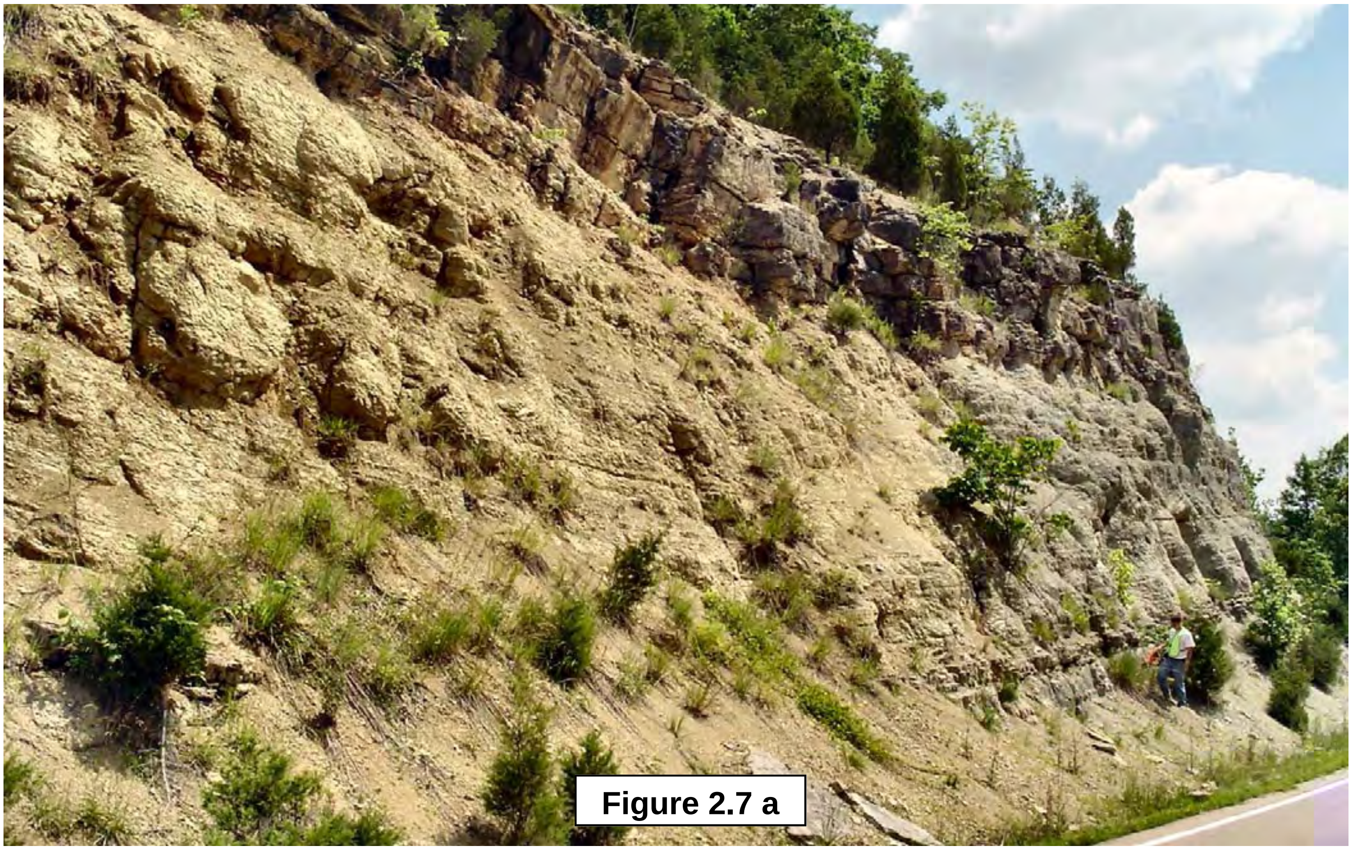


Figure 2.7 a

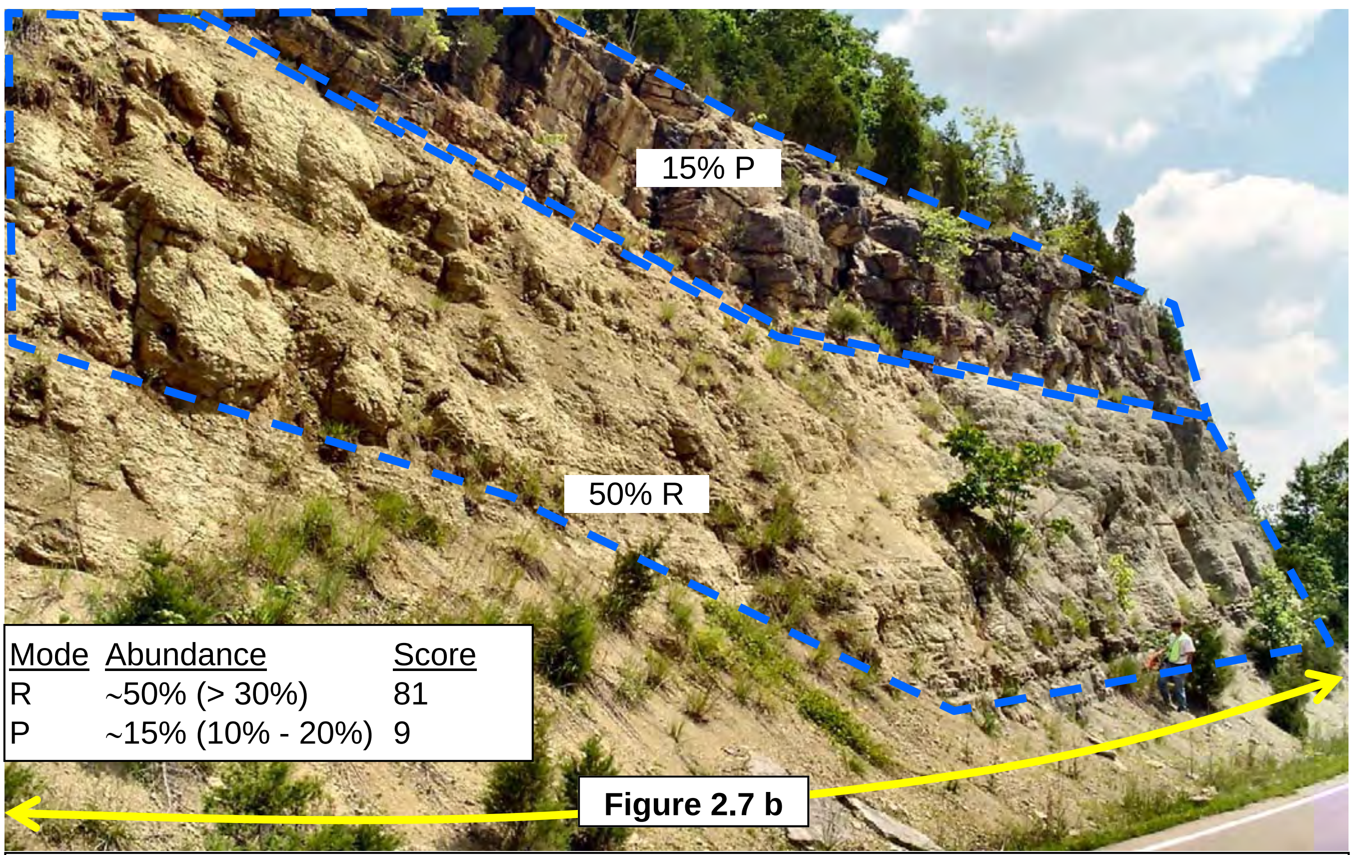
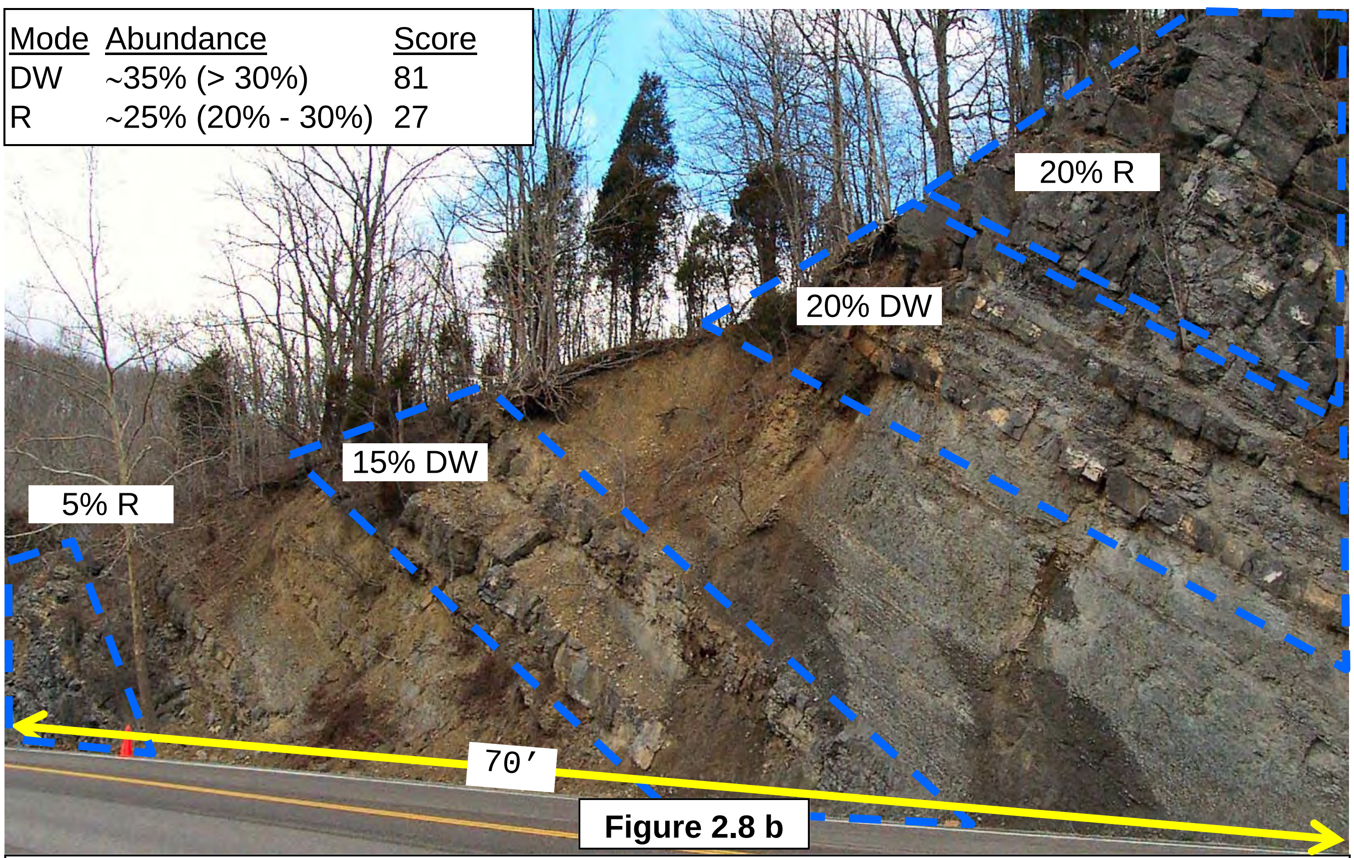


Figure 2.7 b

Potential for toppling is observed in the upper section of the cut. The rest of the cut above the lower dashed line shows small block size raveling. For the length of cut shown, approximately 15 % of the rock face has the potential to fail by planar sliding, and approximately 50% of the rockcut has the potential for raveling.
(Claiborn, SR063, MM 36-60)

Figure 2.8 a



Mode	Abundance	Score
DW	~35% (> 30%)	81
R	~25% (20% - 30%)	27

Figure 2.8 b

Note the different layer characteristics in sections identified as DW. Boundaries of sections that are identified as DW include adjacent layers that are directly affected by non-uniform weathering behavior. Raveling is identified at the top right and the bottom left of the slope. The remainder of the slope is considered stable.
(Grainger County, SR 032, MM 16-30)

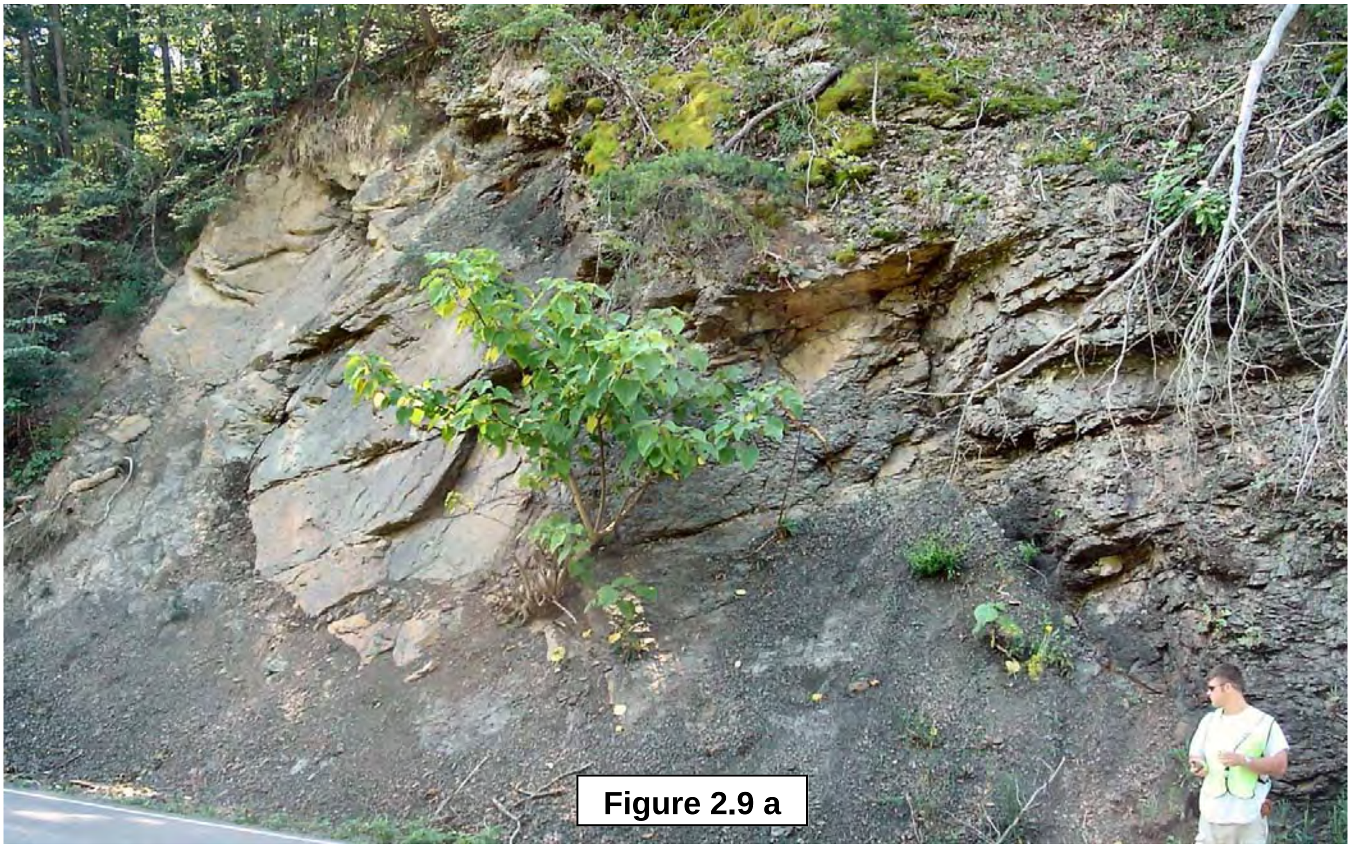
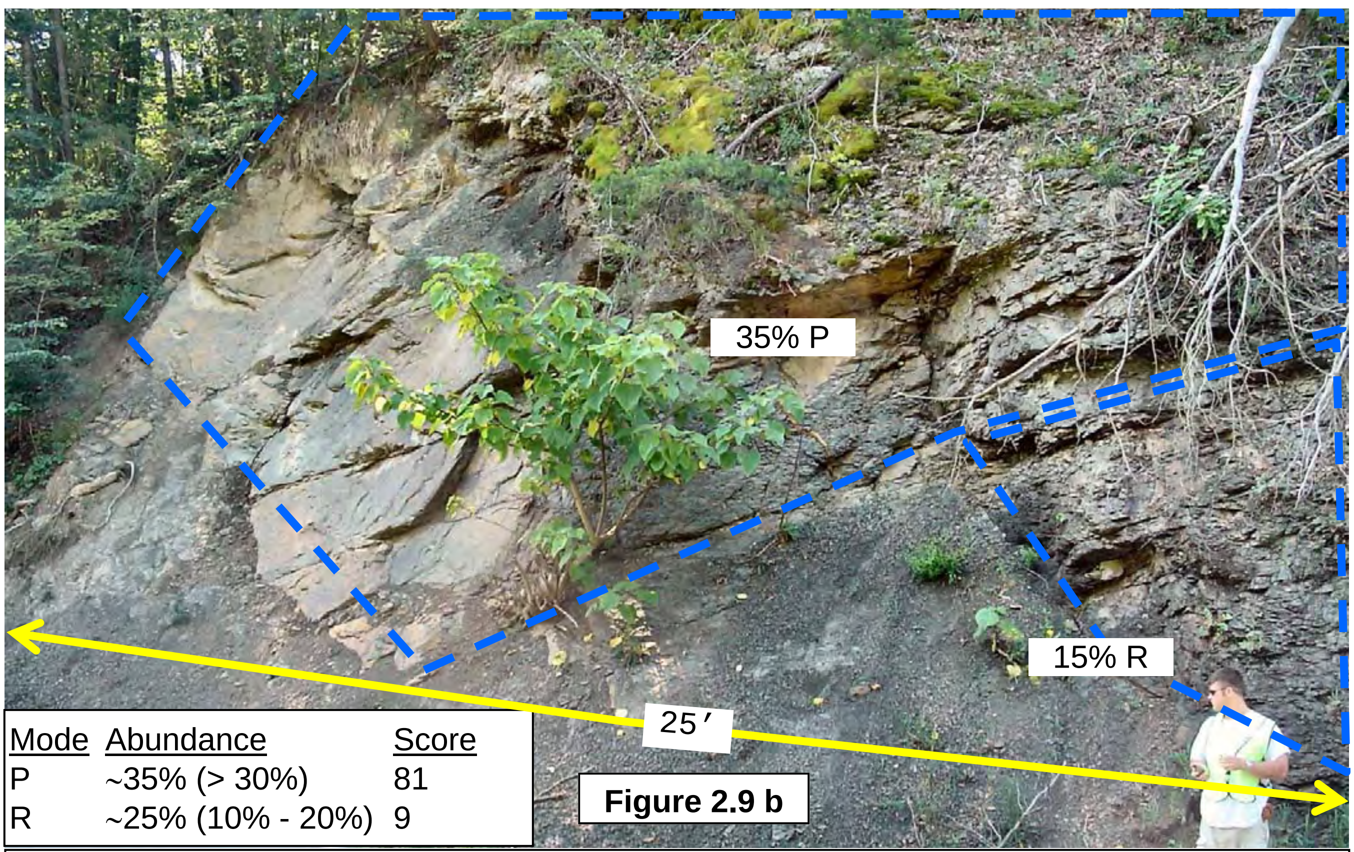


Figure 2.9 a



Mode	Abundance	Score
P	~35% (> 30%)	81
R	~25% (10% - 20%)	9

Figure 2.9 b

This slope has the potential to fail by plane sliding. Rock on the lower right is presently failing by raveling. For the length of cut shown, approximately 35 % of the rock face has the potential to fail by planar sliding, and approximately 15% of the rockcut has the potential for raveling.
(Hancock, SR033, MM 00-27)

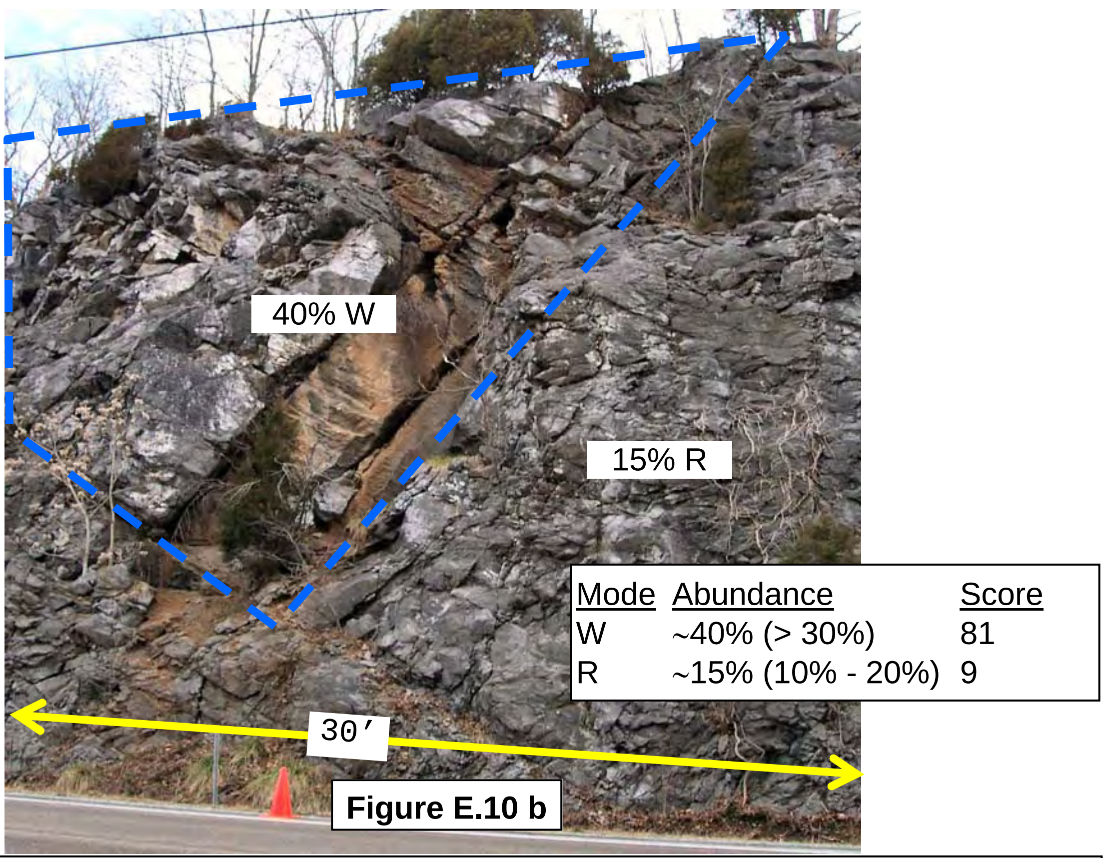


Figure E.10 b

Potential wedge failure is identified at the middle section of the cut. Most of the rest of the rock face is stable, with limited areas subject to raveling. For the length of cut shown, it was estimated that 40% of the cut has the potential to fail by wedge sliding, and 15% by raveling.
(Grainger County, SR 032, MM 16-30)

Chapter 3:

Geologic Failure Mode Identification & Abundance Assessment

Exercises

The purpose of chapter 3 is to serve as training exercises in identifying five potential failure modes specified in the Tennessee Rockfall Hazard Rating System and abundance of each identified mode.

Combined total of 60 drawings and pictures are presented in this exercise.

Instructions

(1) Using the provided failure modes definitions and failure modes identification chart identify the failure mode(s) of each drawing and picture within.

Following abbreviations should be used for recording identified potential failure modes:

P	for Planar slide
W	for Wedge slide
T	for Topple failure
DW	for Differential Weathering
R	for Raveling

(2) Determine the abundance of each identified mode (Abundance is expressed in terms of percentage). Bins for abundance follow the Tennessee RMS Field Sheet.

These bins are, **< 10%, 10—20%, 20—30%, > 30%.**

Chart 3.1 - Failure Modes Definition Chart

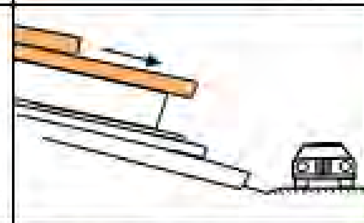
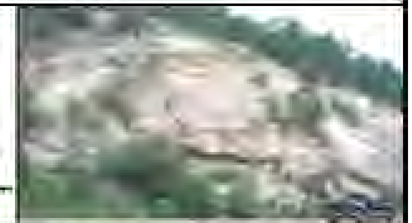
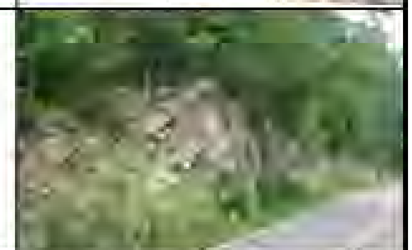
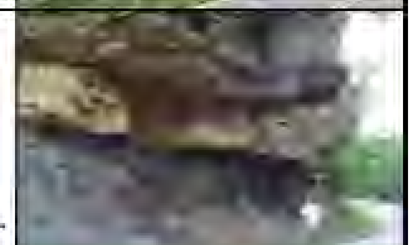
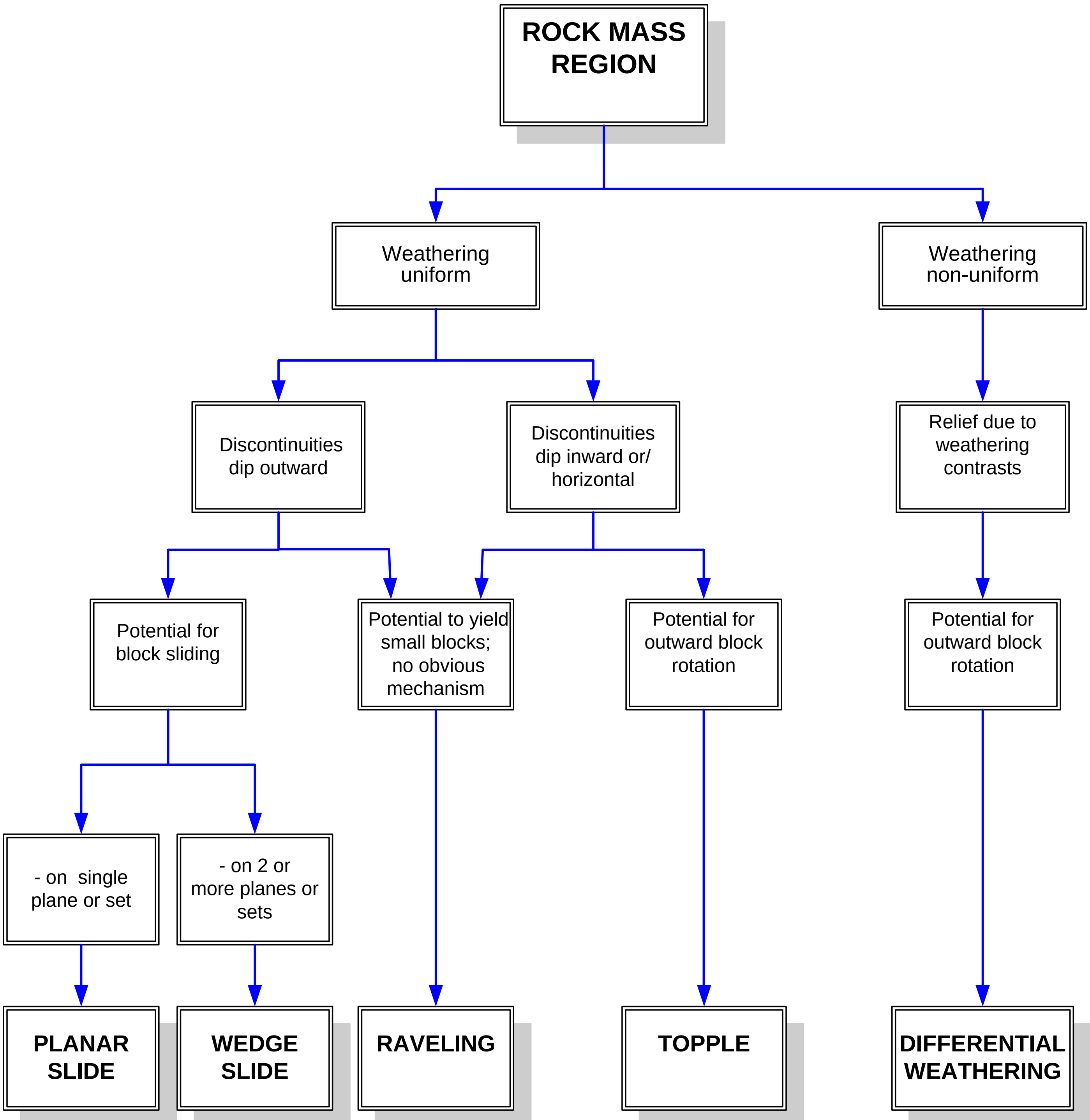
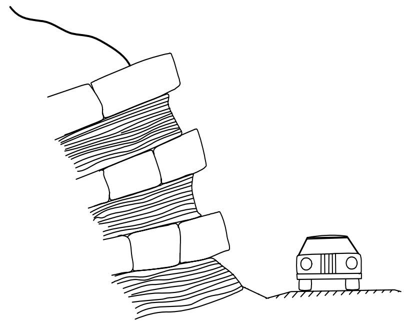
Failure Mode	Characteristics	Illustration
Planar Slide	1. Discontinuities dip towards and daylight on rock face. 2. Blocks have potential to slide on a single inclined plane or set of parallel inclined planes.	 
Wedge Slide	1. Line of intersection of surfaces plunges toward roadway and daylights on rock face. 2. Blocks have potential to slide on two or more inclined non-parallel surfaces.	 
Topple	1. Rock mass is layered, with layers striking sub-parallel to road and dipping away from road, or with layers horizontal. 2. Potential movement is forward rotation of layers.	 
Differential Weathering	1. Rock mass exhibits non-uniform weathering characteristics and localized relief. 2. Weathering contrasts create potential for adjacent blocks to rotate out.	 
Raveling	1. Weathering results in gradual decomposition of rock mass. 2. Progressive loosening and shedding of blocks by no distinct sliding or rotational mechanism.	 

Chart 3.2 - Failure Modes Identification Chart



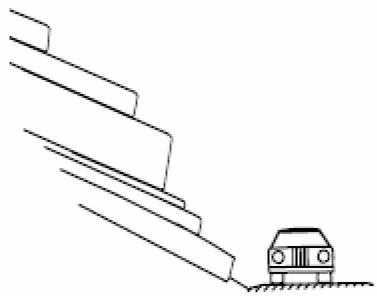
1



Failure Mode	Abundance (%)

Comments

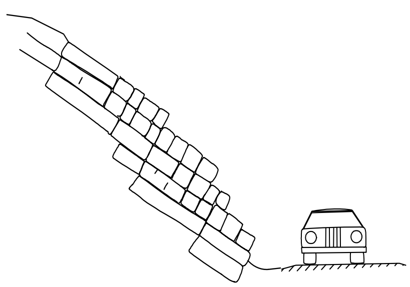
2



Failure Mode	Abundance (%)

Comments

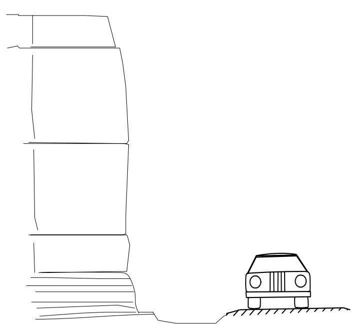
3



Failure Mode	Abundance (%)

Comments

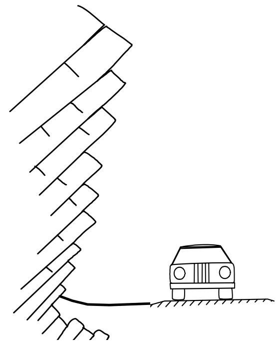
4



Failure Mode	Abundance (%)

Comments

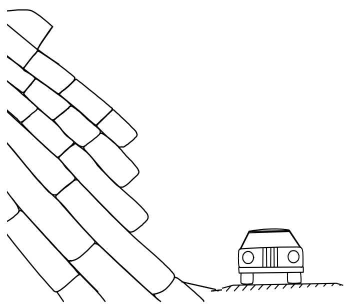
5



Failure Mode	Abundance (%)

Comments

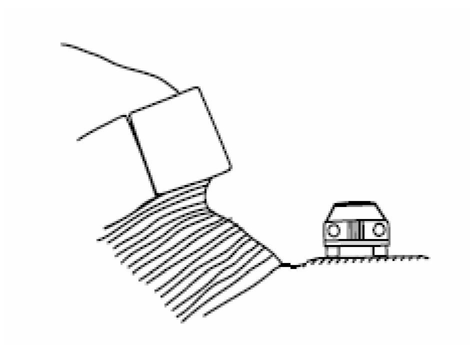
6



Failure Mode	Abundance (%)

Comments

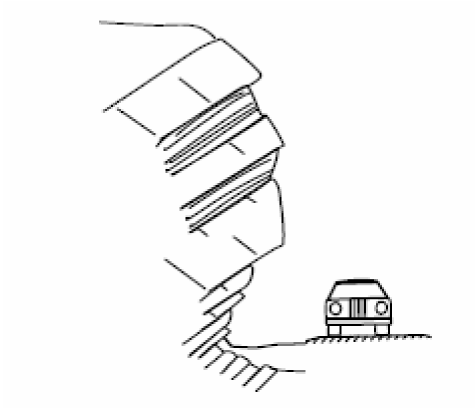
7



Failure Mode	Abundance (%)

Comments

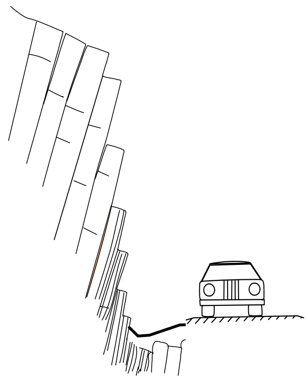
8



Failure Mode	Abundance (%)

Comments

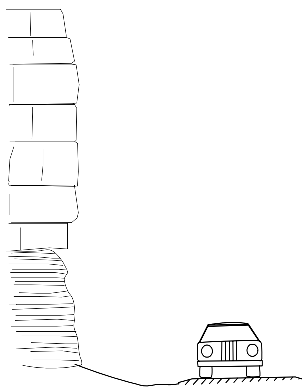
9



Failure Mode	Abundance (%)

Comments

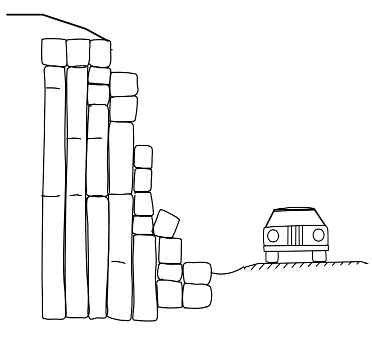
10



Failure Mode	Abundance (%)

Comments

11



Failure Mode	Abundance (%)

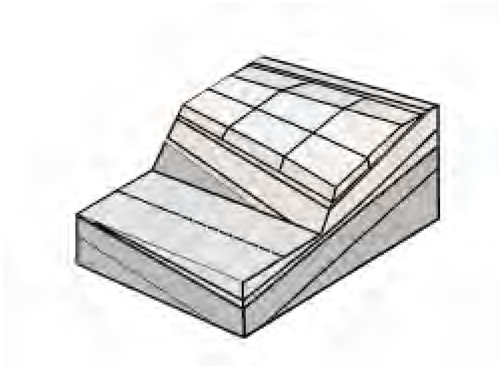
Comments

12

Failure Mode	Abundance (%)

Comments

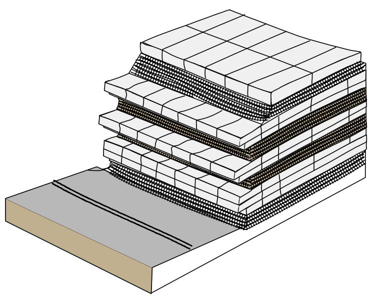
13



Failure Mode	Abundance (%)

Comments

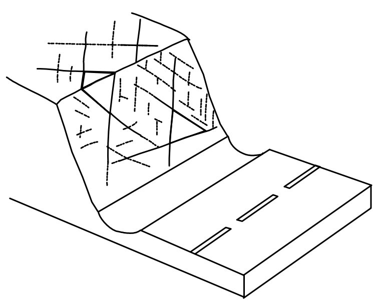
14



Failure Mode	Abundance (%)

Comments

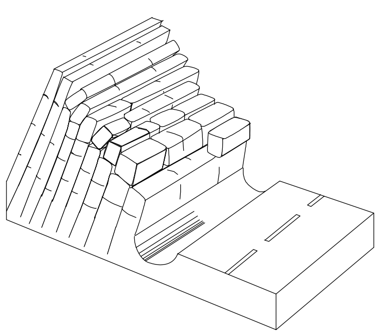
15



Failure Mode	Abundance (%)

Comments

16



Failure Mode	Abundance (%)

Comments

17

Failure Mode	Abundance (%)

Comments

18

Failure Mode	Abundance (%)

Comments

19

Failure Mode	Abundance (%)

Comments

20

Failure Mode	Abundance (%)

Comments

21

Failure Mode	Abundance (%)

Comments

22

Failure Mode	Abundance (%)

Comments

23

Failure Mode	Abundance (%)

Comments

24

Failure Mode	Abundance (%)

Comments

25

Failure Mode	Abundance (%)

Comments

26

Failure Mode	Abundance (%)

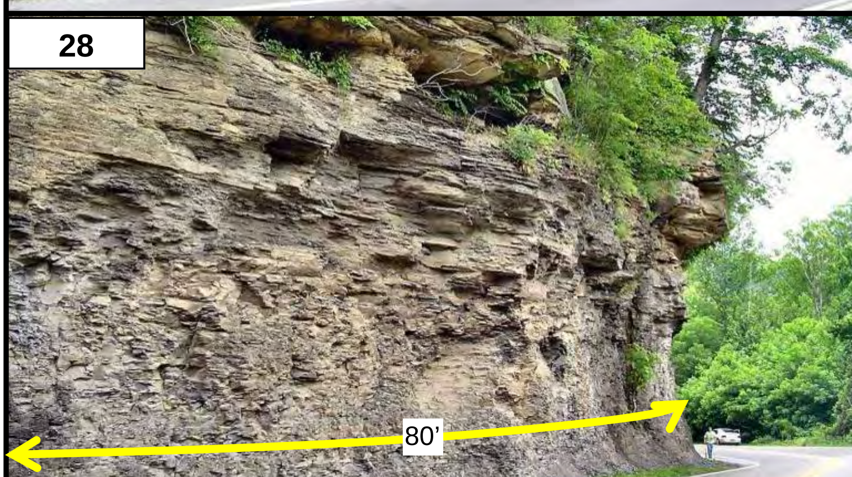
Comments

27

Failure Mode	Abundance (%)

Comments

28



Failure Mode	Abundance (%)

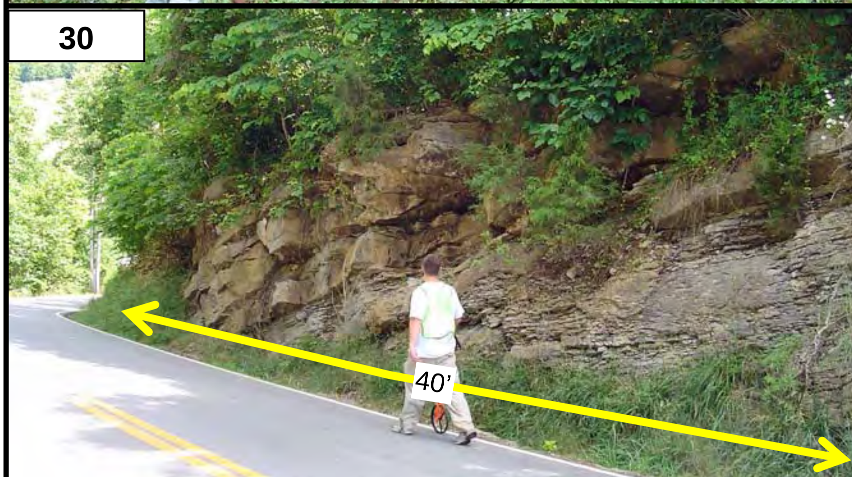
Comments

29

Failure Mode	Abundance (%)

Comments

30



Failure Mode	Abundance (%)

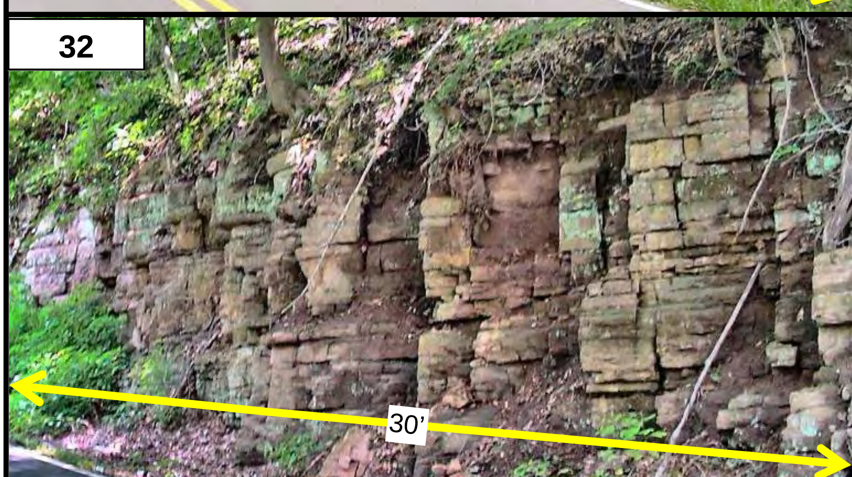
Comments

31

Failure Mode	Abundance (%)
	<

Comments

32



Failure Mode	Abundance (%)

Comments

33

Failure Mode	Abundance (%)

Comments

34

Failure Mode	Abundance (%)

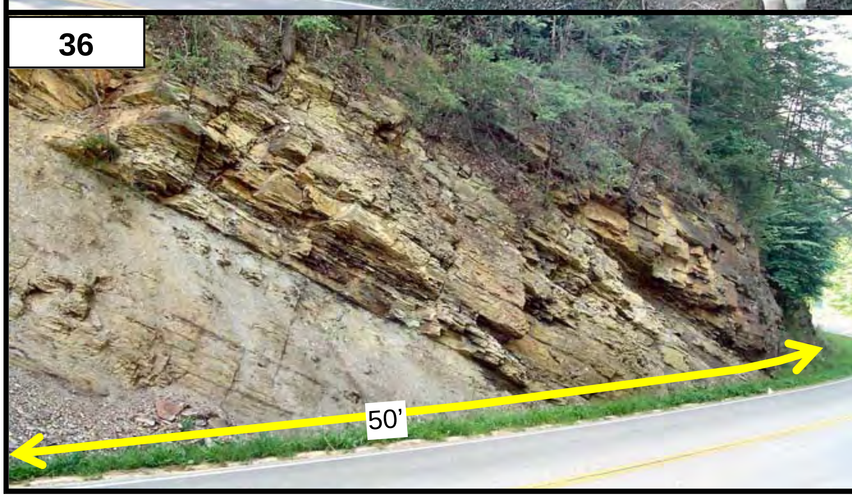
Comments

35

Failure Mode	Abundance (%)

Comments

36



Failure Mode	Abundance (%)

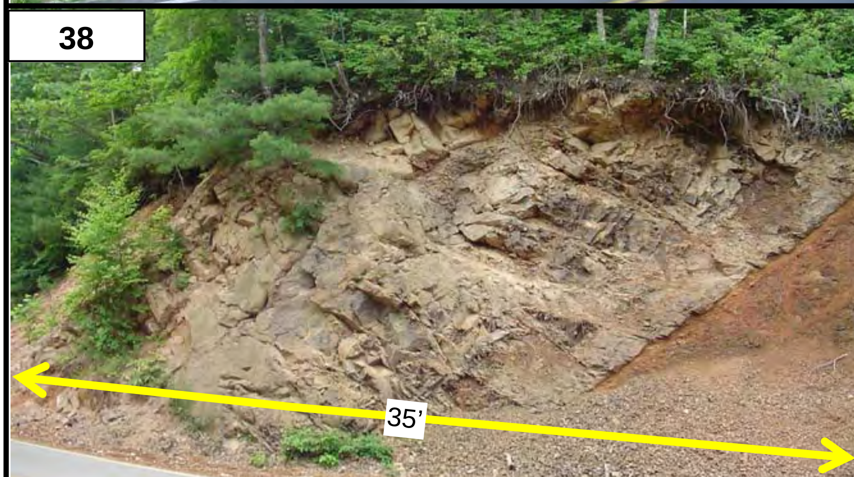
Comments

37

Failure Mode	Abundance (%)

Comments

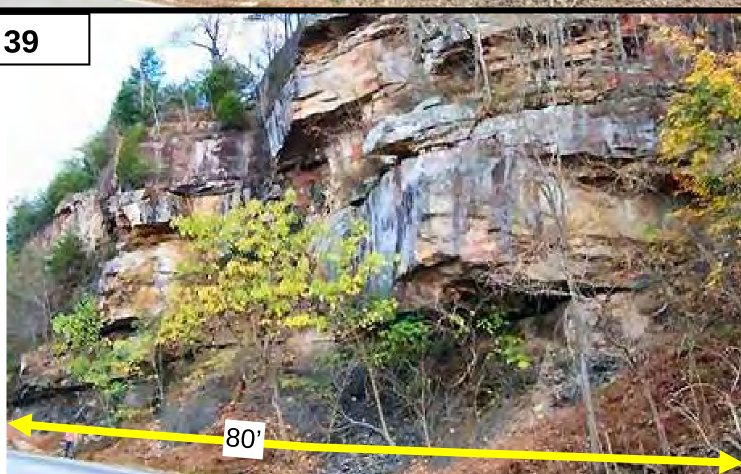
38



Failure Mode	Abundance (%)

Comments

39



Failure Mode	Abundance (%)

Comments

40

Failure Mode	Abundance (%)

Comments

41

Failure Mode	Abundance (%)

Comments

42

Failure Mode	Abundance (%)

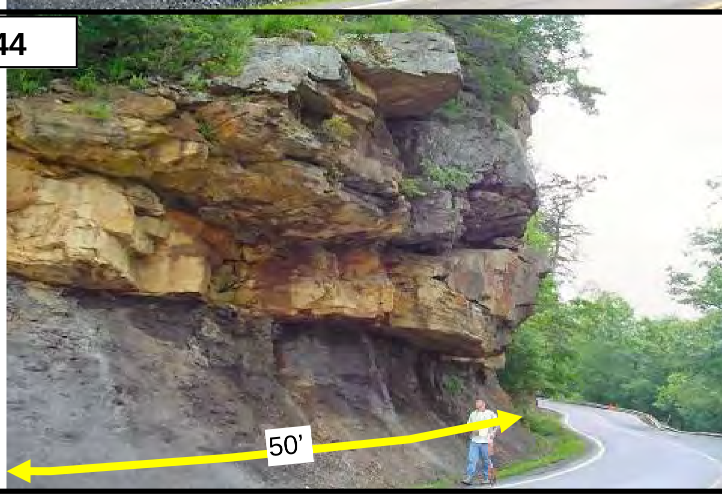
Comments

43

Failure Mode	Abundance (%)

Comments

44



Failure Mode	Abundance (%)

Comments

45

Failure Mode	Abundance (%)

Comments

46

Failure Mode	Abundance (%)

Comments

47

Failure Mode	Abundance (%)

Comments

48

Failure Mode	Abundance (%)

Comments

49

Failure Mode	Abundance (%)

Comments

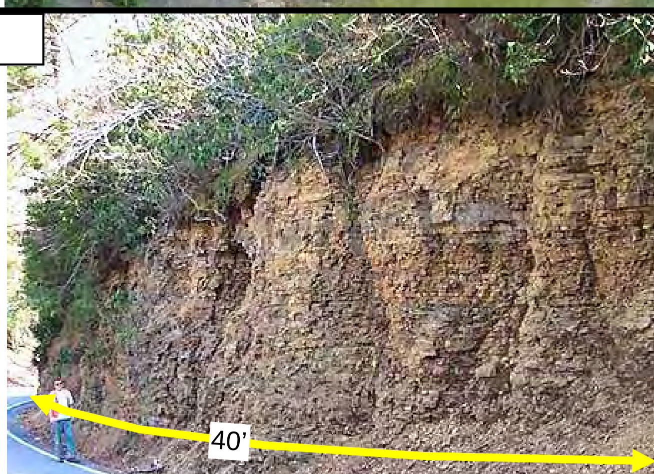
50

Failure Mode	Abundance (%)

Comments

B-slope

51



Failure Mode	Abundance (%)

Comments

52

Failure Mode	Abundance (%)

Comments

53

Failure Mode	Abundance (%)

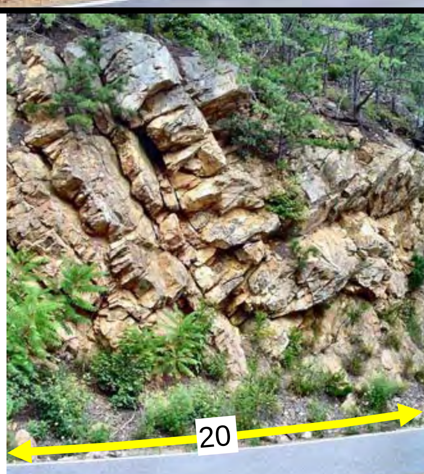
Comments

54

Failure Mode	Abundance (%)

Comments

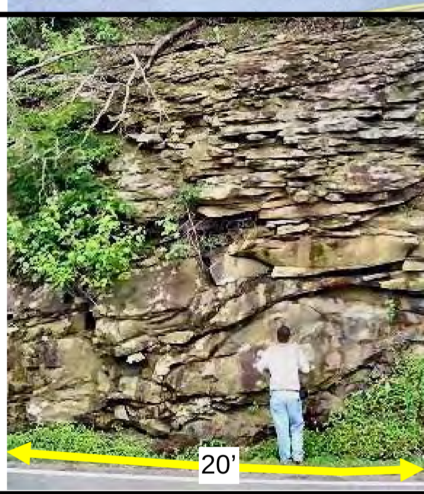
55



Failure Mode	Abundance (%)

Comments

56



Failure Mode	Abundance (%)

Comments

57

Failure Mode	Abundance (%)

Comments

58

Failure Mode	Abundance (%)

Comments

59

Failure Mode	Abundance (%)

Comments

60

Failure Mode	Abundance (%)

Comments

Chapter 3.1:

Geologic Failure Mode Identification & Abundance Assessment

Exercises

(Solution Key)

The purpose of chapter 3 is to serve as training exercises in identifying five potential failure modes specified in the Tennessee Rockfall Hazard Rating System and abundance of each identified mode.

Combined total of 60 drawings and pictures are presented in this exercise.

Instructions

(1) Using the provided failure modes definitions and failure modes identification chart identify the failure mode(s) of each drawing and picture within.

Following abbreviations should be used for recording identified potential failure modes:

P	for Planar slide
W	for Wedge slide
T	for Topple failure
DW	for Differential Weathering
R	for Raveling

(2) Determine the abundance of each identified mode (Abundance is expressed in terms of percentage). Bins for abundance follow the Tennessee RMS Field Sheet.

These bins are, **< 10%, 10—20%, 20—30%, > 30%.**

Chart 3.1 - Failure Modes Definition Chart

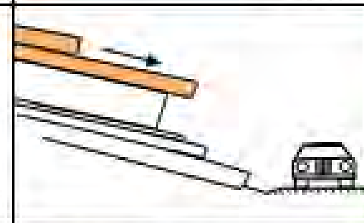
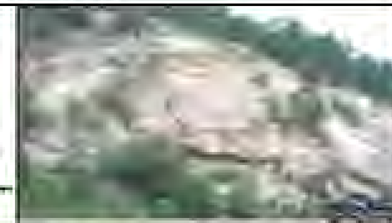
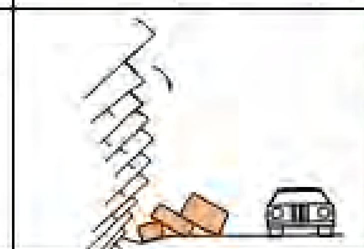
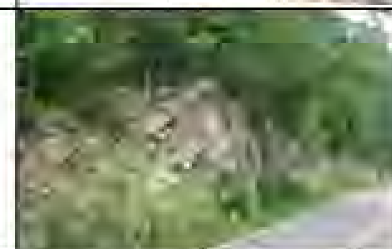
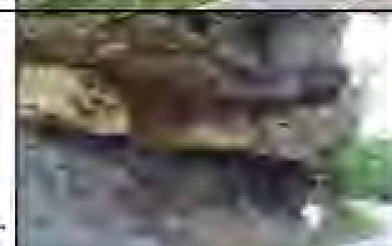
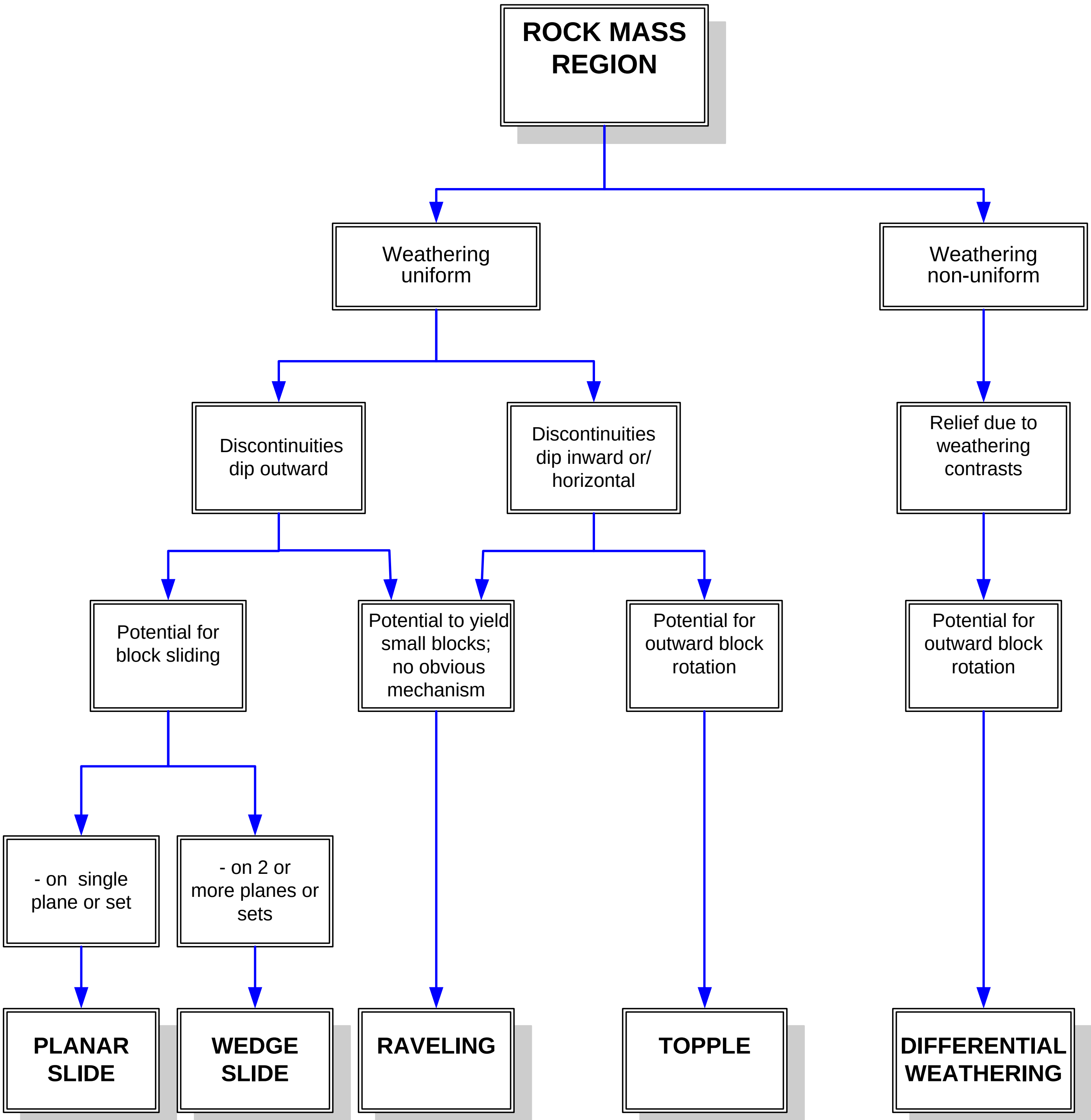
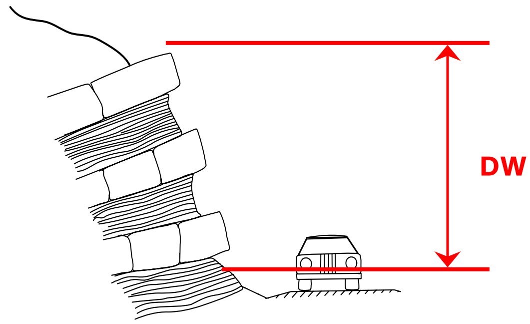
Failure Mode	Characteristics	Illustration	
Planar Slide	1. Discontinuities dip towards and daylight on rock face. 2. Blocks have potential to slide on a single inclined plane or set of parallel inclined planes.		
Wedge Slide	1. Line of intersection of surfaces plunges toward roadway and daylights on rock face. 2. Blocks have potential to slide on two or more inclined non-parallel surfaces.		
Topple	1. Rock mass is layered, with layers striking sub-parallel to road and dipping away from road, or with layers horizontal. 2. Potential movement is forward rotation of layers.		
Differential Weathering	1. Rock mass exhibits non-uniform weathering characteristics and localized relief. 2. Weathering contrasts create potential for adjacent blocks to rotate out.		
Raveling	1. Weathering results in gradual decomposition of rock mass. 2. Progressive loosening and shedding of blocks by no distinct sliding or rotational mechanism.		

Chart 3.2 - Failure Modes Identification Chart



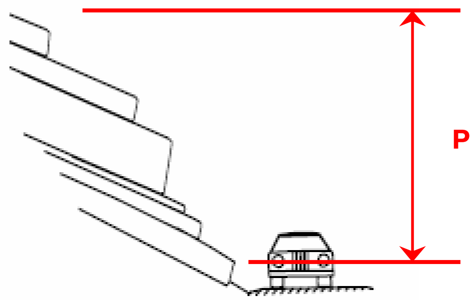
1



Failure Mode	Abundance (%)
DW	>30%

Comments

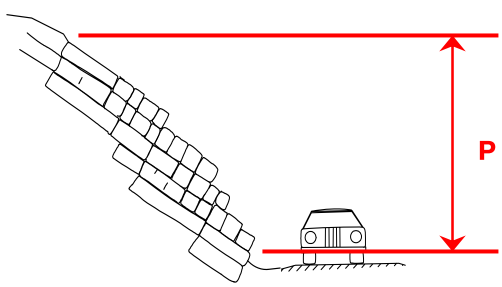
2



Failure Mode	Abundance (%)
P	>30%

Comments

3

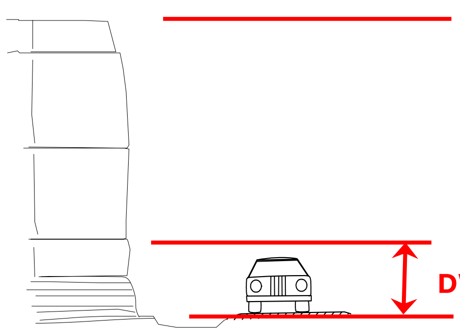


Failure Mode	Abundance (%)
P	>30%

Comments

The initial movement of the blocks is determined to be sliding along the bedding plane which dips towards the road.

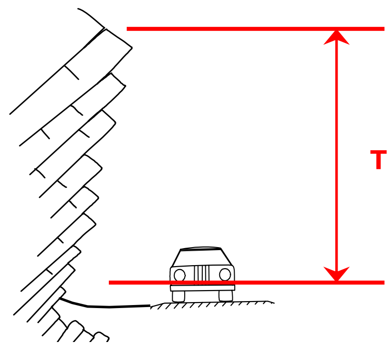
4



Failure Mode	Abundance (%)
DW	10—20%

Comments

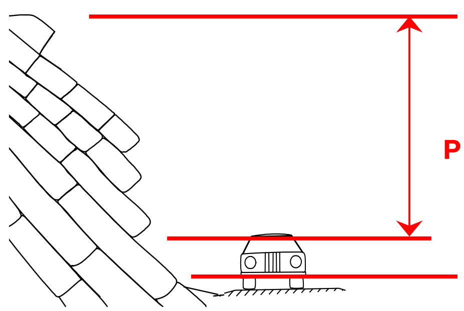
5



Failure Mode	Abundance (%)
T	>30%

Comments

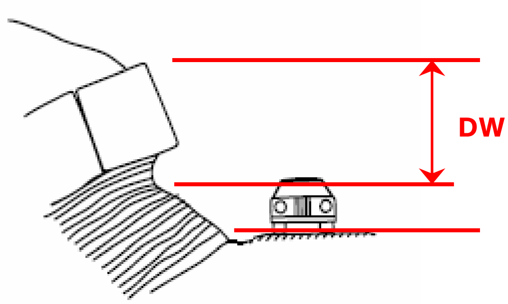
6



Failure Mode	Abundance (%)
P	>30%

Comments

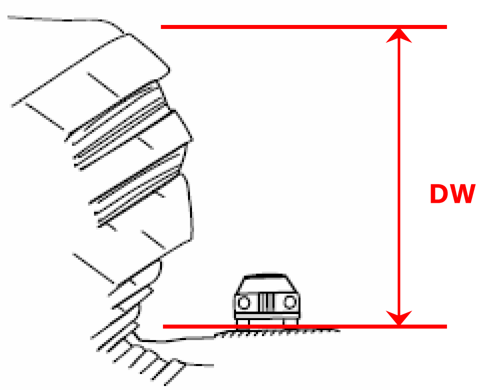
7



Failure Mode	Abundance (%)
DW	>30%

Comments

8

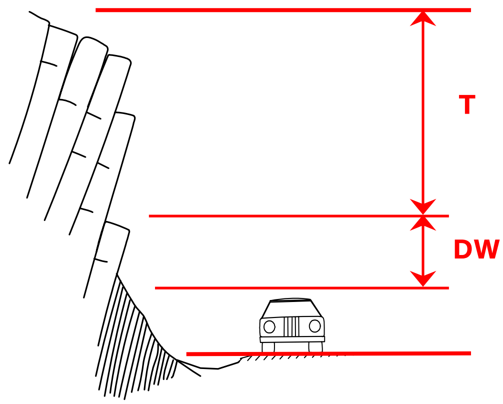


Failure Mode	Abundance (%)
DW	>30%

Comments

Three lithologies can be seen with different weathering rates.

9

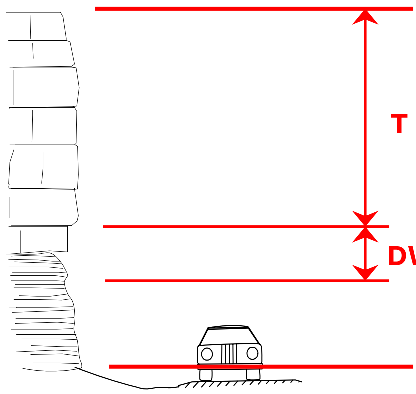


Failure Mode	Abundance (%)
DW	20—30%
T	>30%

Comments

Two lithologies are identified. Note that only the first layer of the more competent unit which is deem to be directly affected by differential weathering is rated as DW.

10

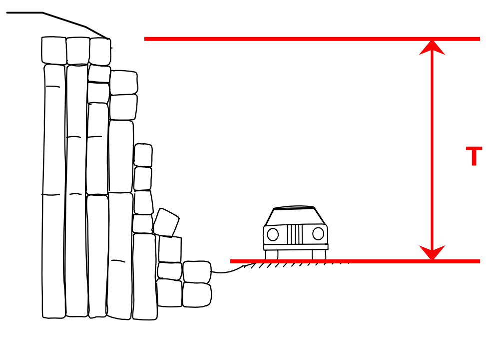


Failure Mode	Abundance (%)
DW	10—20%
T	>30%

Comments

Two lithologies are identified. Only the first distinct layer of the more competent unit will fail as a direct result of different weathering rates.

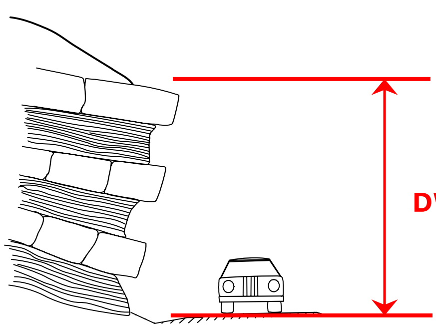
11



Failure Mode	Abundance (%)
T	>30%

Comments

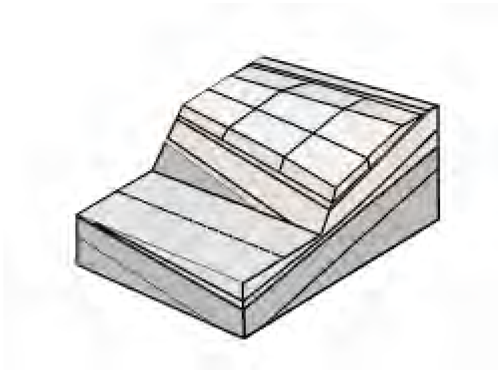
12



Failure Mode	Abundance (%)
DW	>30%

Comments

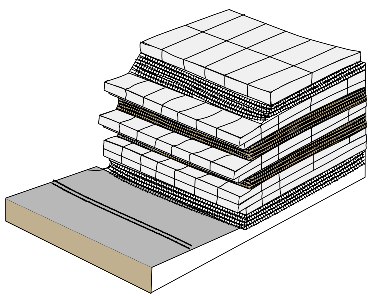
13



Failure Mode	Abundance (%)
P	20—30%

Comments
Most of the slope is stable except the top of the slope.

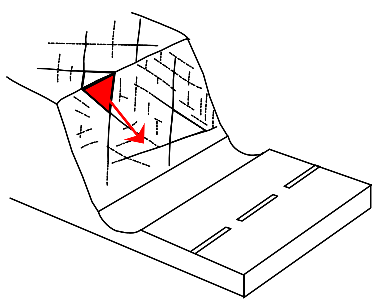
14



Failure Mode	Abundance (%)
DW	>30%

Comments

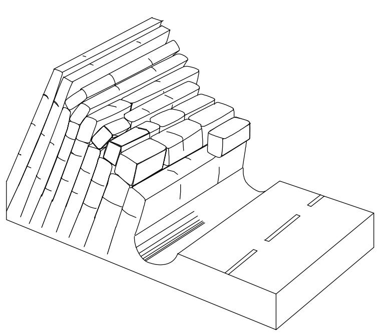
15



Failure Mode	Abundance (%)
W	10—20%

Comments

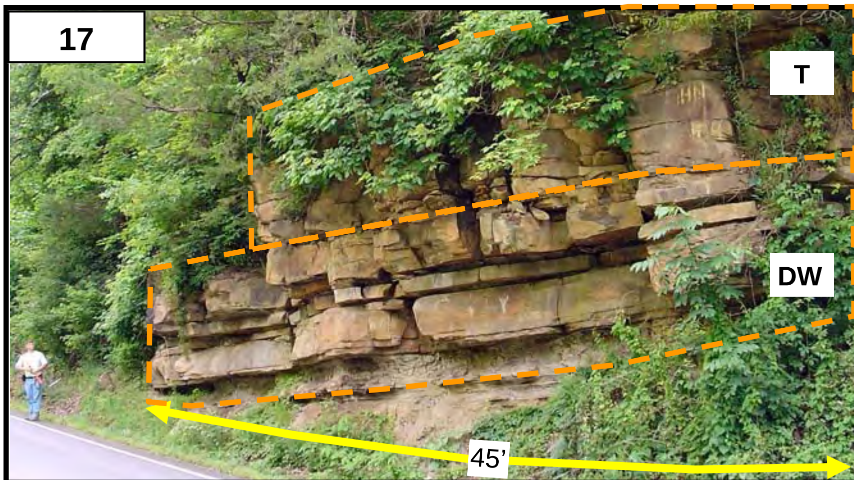
16



Failure Mode	Abundance (%)
T	>30%

Comments

17



Failure Mode	Abundance (%)
DW	>30%
T	>30%

Comments

18

Failure Mode	Abundance (%)
DW	10—20%
R	< 10%

Comments

19

Failure Mode	Abundance (%)
P	20—30%

Comments

Most of the rockcut shows the potential for planar slide failure.

20

Failure Mode	Abundance (%)
P	20—30%

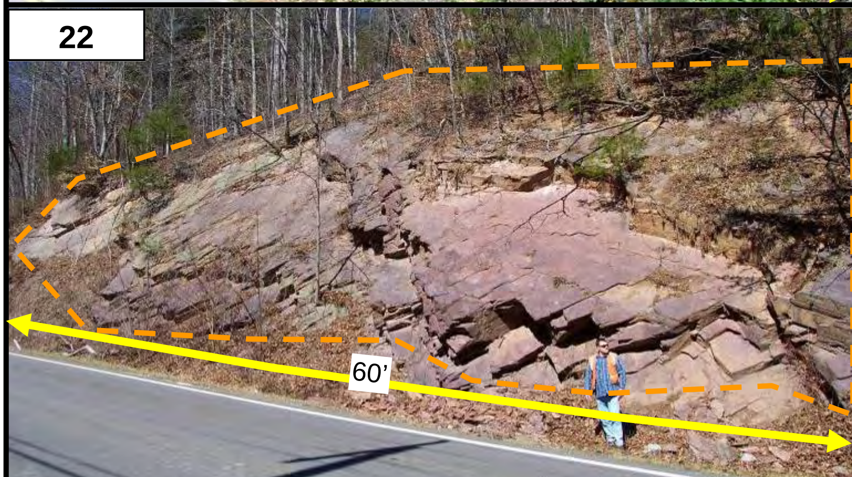
Comments

21

Failure Mode	Abundance (%)
T	>30%
R	20—30%

Comments

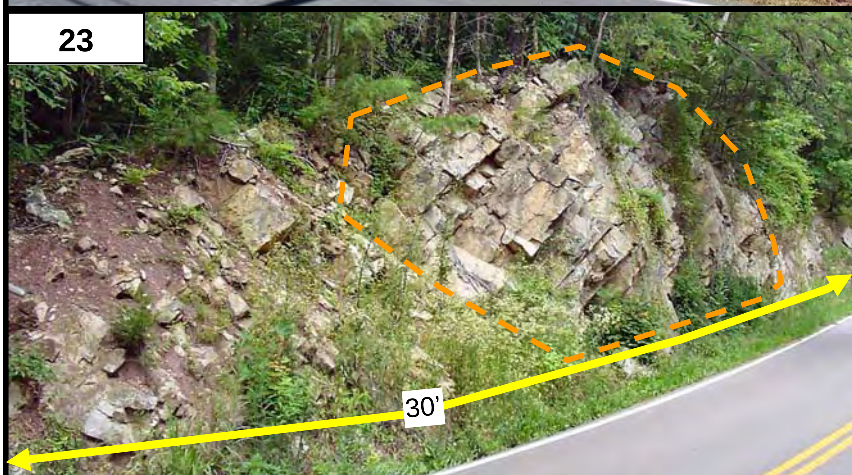
22



Failure Mode	Abundance (%)
P	>30%

Comments

23



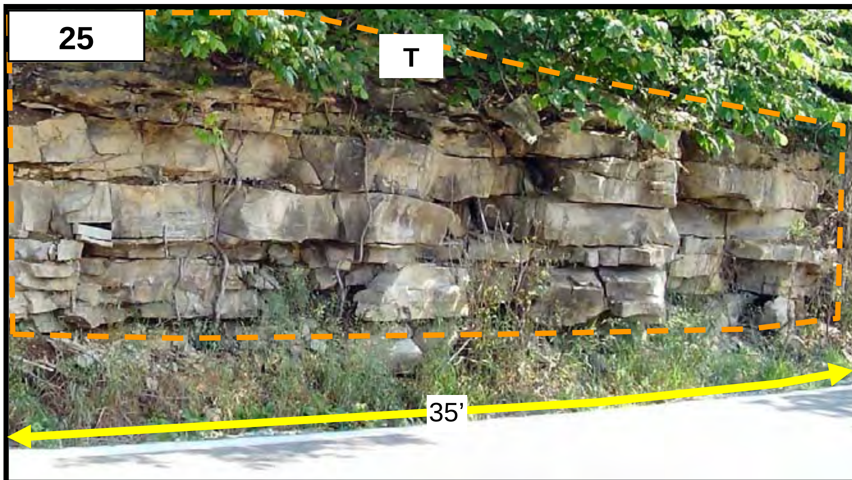
Failure Mode	Abundance (%)
T	>30%

Comments

24

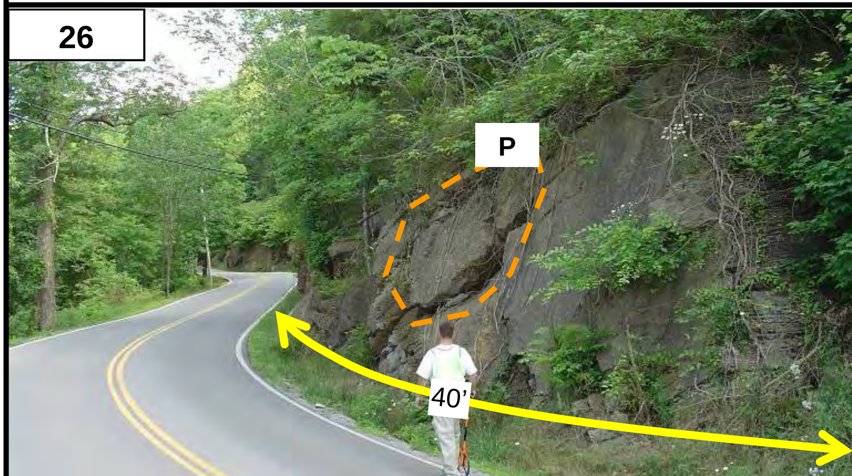
Failure Mode	Abundance (%)
P	>30%

Comments
The entire slope shows the potential for planar failure.



Failure Mode	Abundance (%)
T	>30%

Comments
Most of the slope shows the potential for bedding release failure.

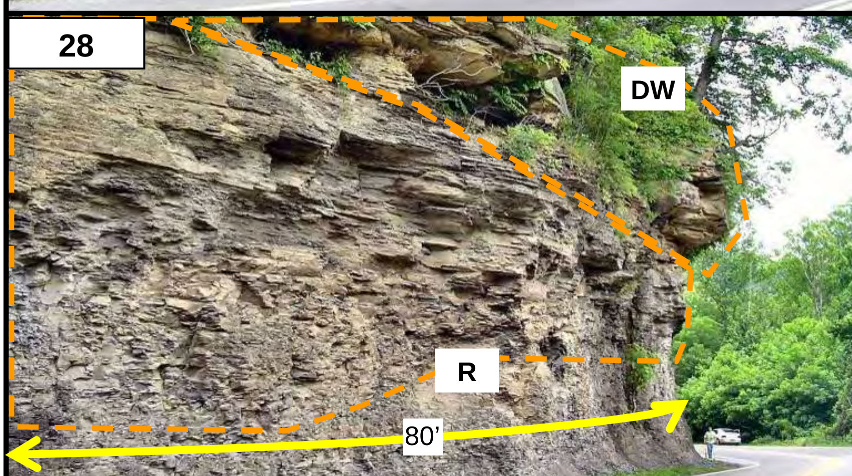


Failure Mode	Abundance (%)
P	<10%

Comments

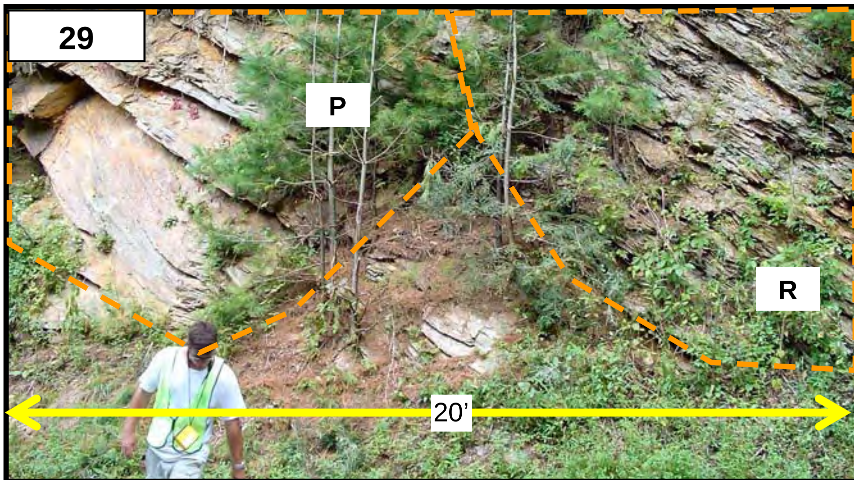
Failure Mode	Abundance (%)
R	> 30%

Comments
The entire slope has potential for shedding rocks onto the road.



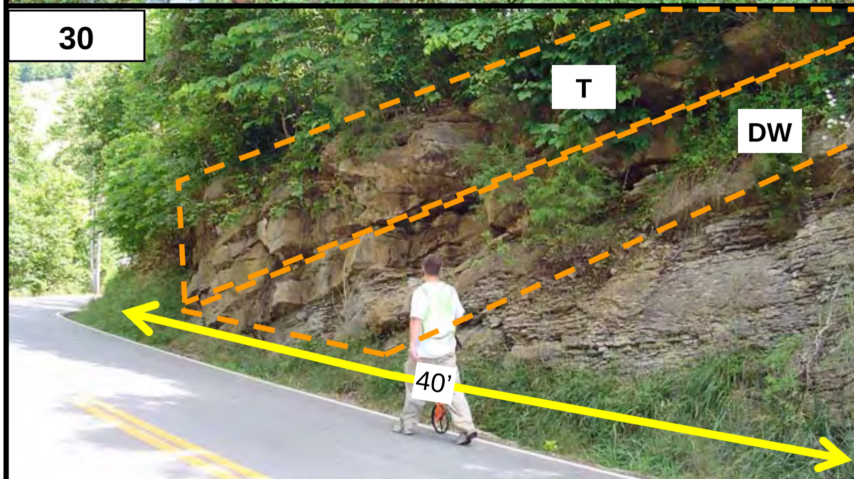
Failure Mode	Abundance (%)
DW	10—20%
R	>30%

Comments



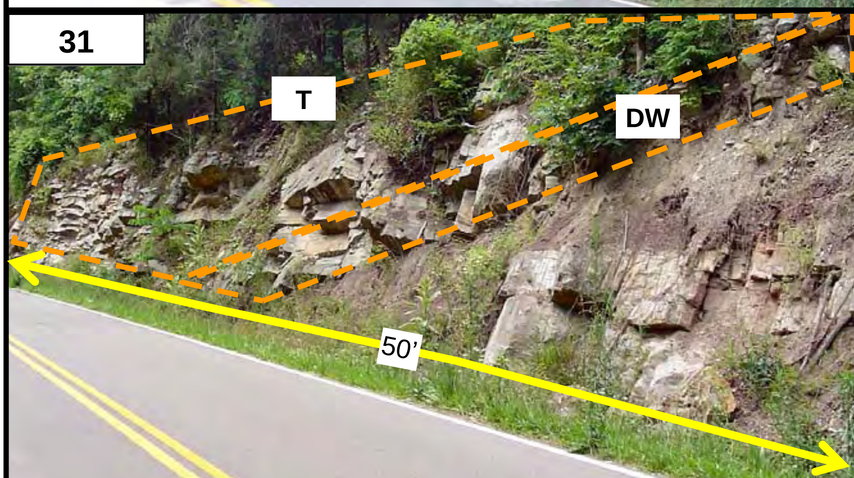
Failure Mode	Abundance (%)
P	>30%
R	>30%

Comments



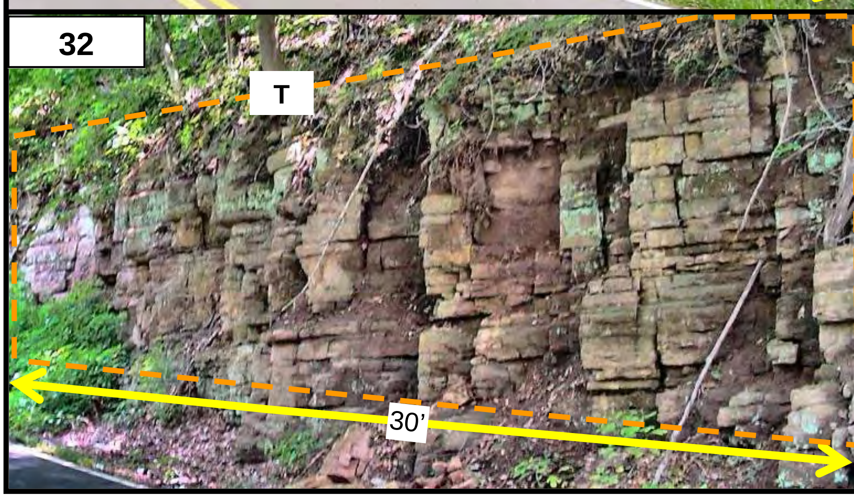
Failure Mode	Abundance (%)
DW	20—30%
T	20—30%

Comments



Failure Mode	Abundance (%)
T	>30%
DW	<10%

Comments



Failure Mode	Abundance (%)
T	>30%

Comments

33

Failure Mode	Abundance (%)
DW	>30%

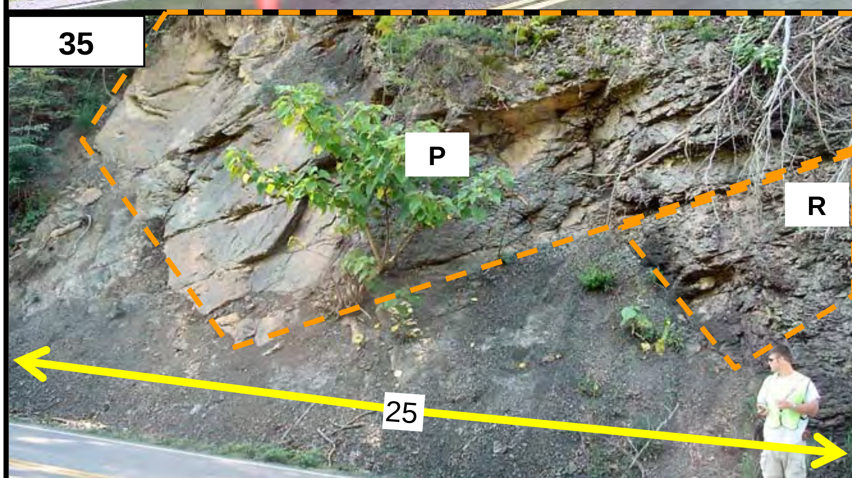
Comments

34

Failure Mode	Abundance (%)
P	>30%

Comments

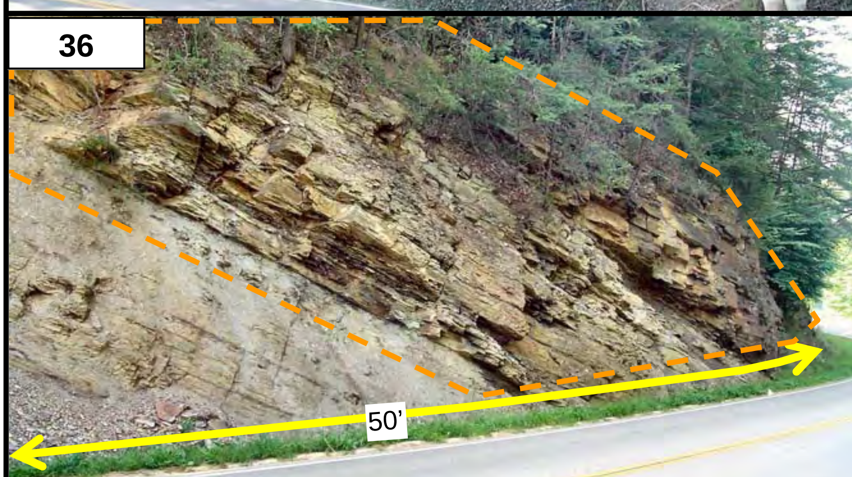
35



Failure Mode	Abundance (%)
P	>30%
R	10—20%

Comments

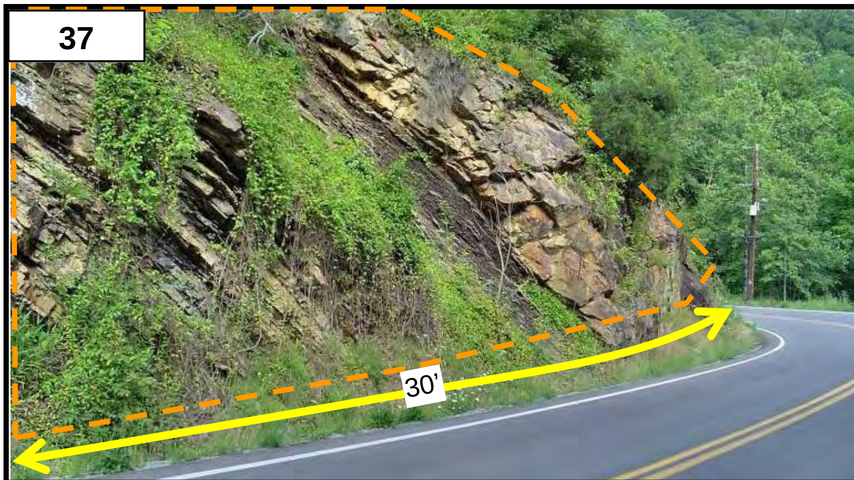
36



Failure Mode	Abundance (%)
DW	>30%

Comments
3 different lithologies with different weathering rates is shown. The slope should be rated as DW.

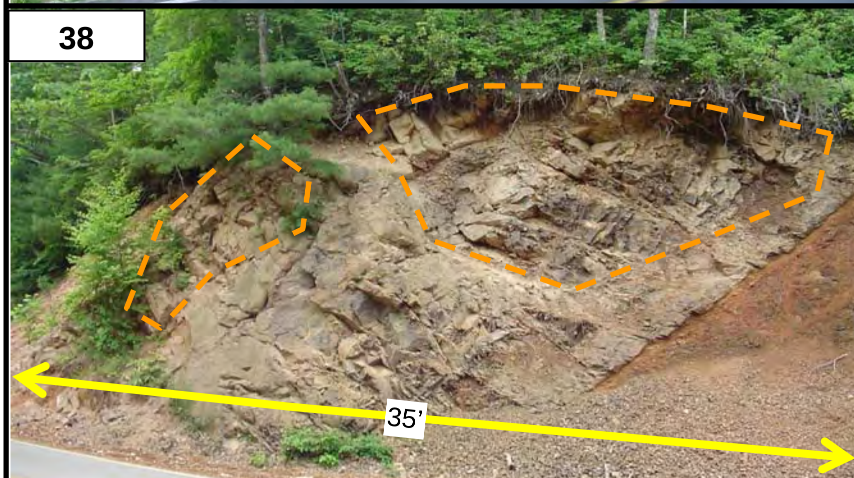
37



Failure Mode	Abundance (%)
DW	>30%

Comments

38



Failure Mode	Abundance (%)
R	10—20%

Comments

39

Failure Mode	Abundance (%)
DW	>30%

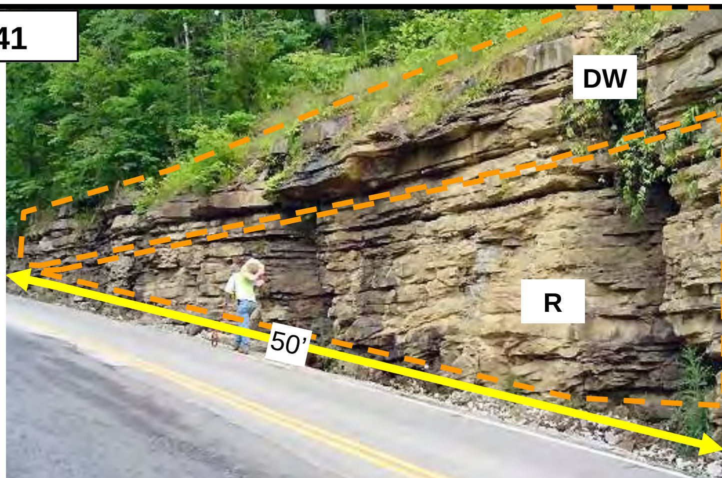
Comments

40

Failure Mode	Abundance (%)
P	>30%

Comments

41



Failure Mode	Abundance (%)
DW	20—30%
R	>30%

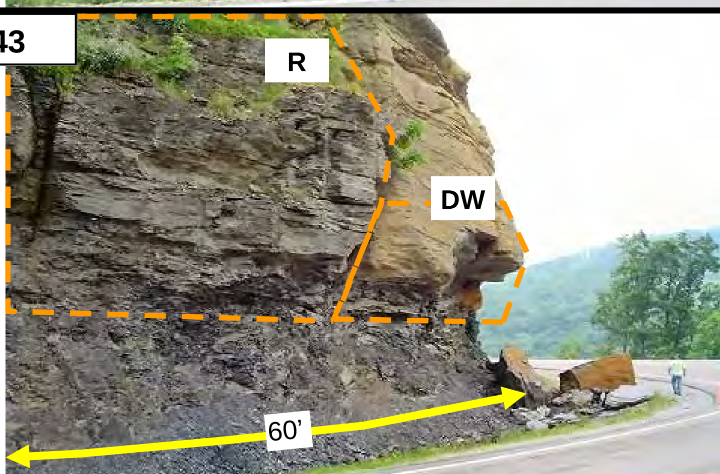
Comments

42

Failure Mode	Abundance (%)
P	<10%
R	10—20%

Comments

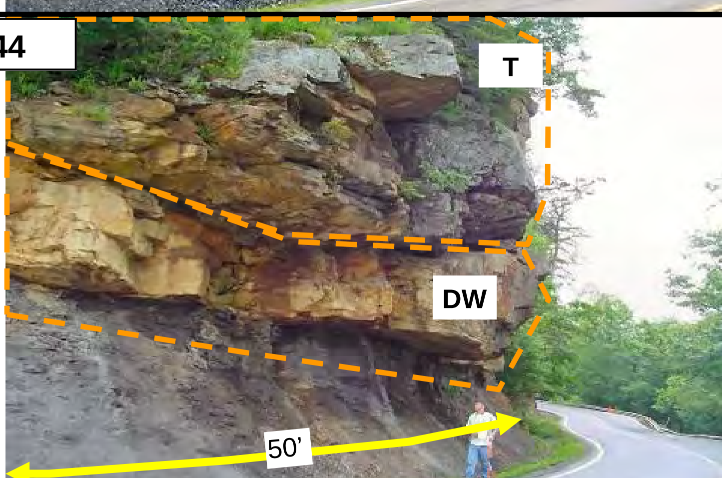
43



Failure Mode	Abundance (%)
DW	<10%
R	20—30%

Comments

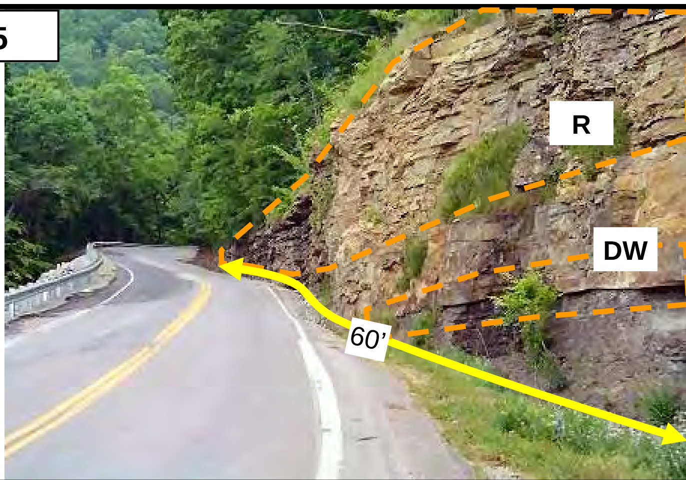
44



Failure Mode	Abundance (%)
DW	20—30%
T	>30%

Comments

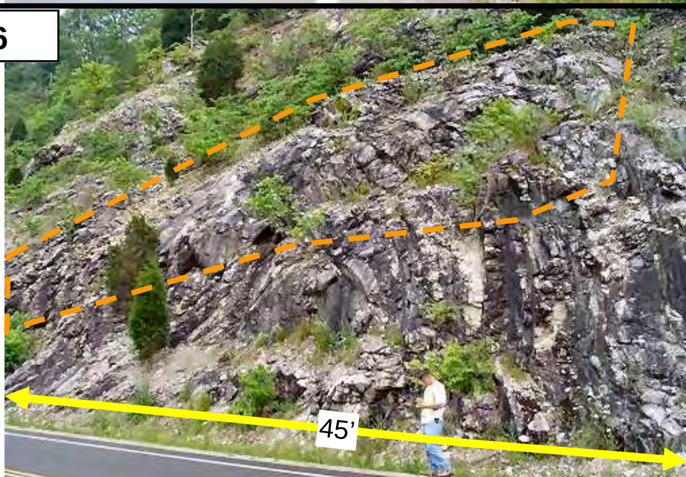
45



Failure Mode	Abundance (%)
DW	<10%
R	20—30%

Comments

46



Failure Mode	Abundance (%)
R	20—30%

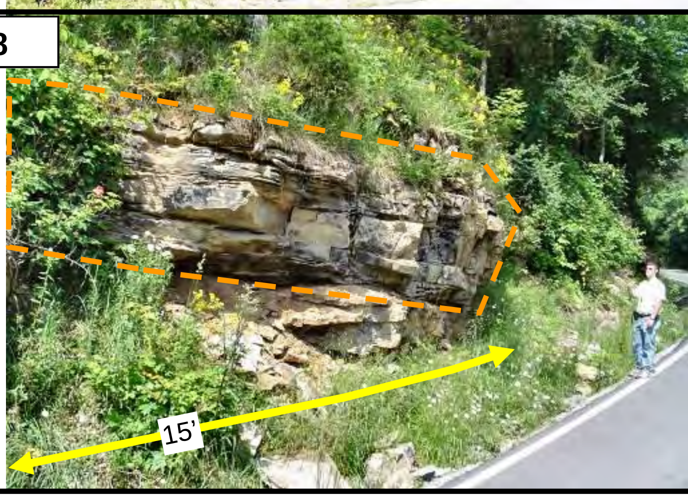
Comments

47

Failure Mode	Abundance (%)
DW	>30%
T	>30%

Comments

48



Failure Mode	Abundance (%)
DW	>30%

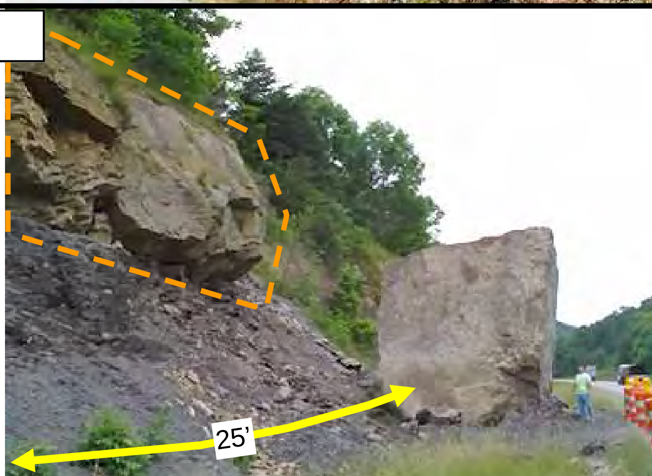
Comments

49

Failure Mode	Abundance (%)
P	>30%

Comments

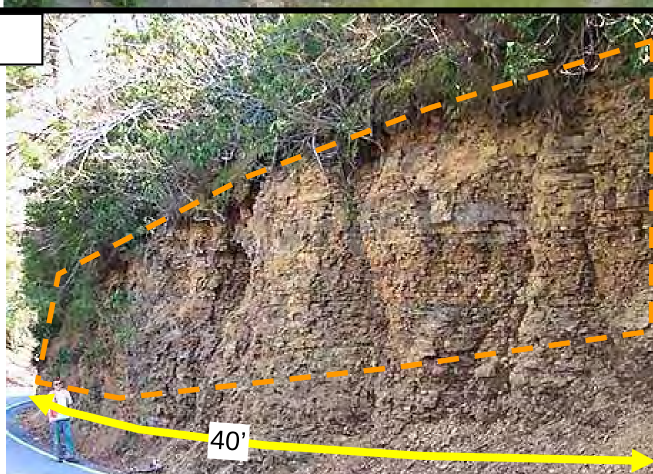
50



Failure Mode	Abundance (%)
DW	>30%

Comments
B-slope

51



Failure Mode	Abundance (%)
R	>30%

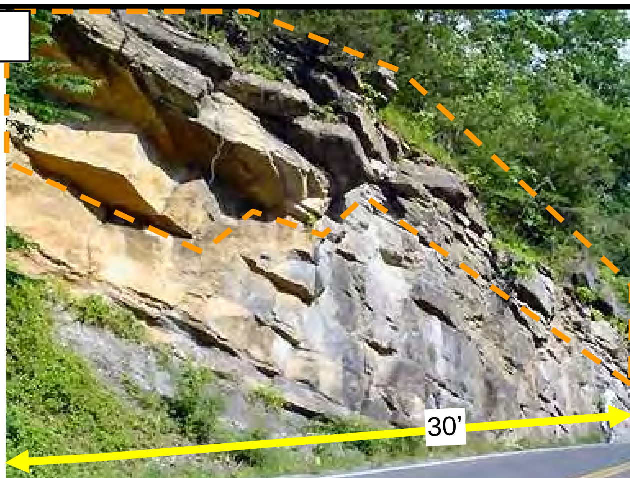
Comments

52

Failure Mode	Abundance (%)
P	10—20%
R	>30%

Comments

53



Failure Mode	Abundance (%)
T	20—30%

Comments

54

Failure Mode	Abundance (%)
R	>30%

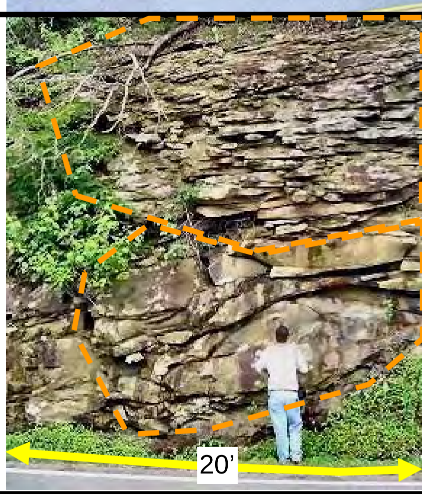
Comments
The slope sheds rocks with no distinct mechanism.

55

Failure Mode	Abundance (%)
W	>30%

Comments

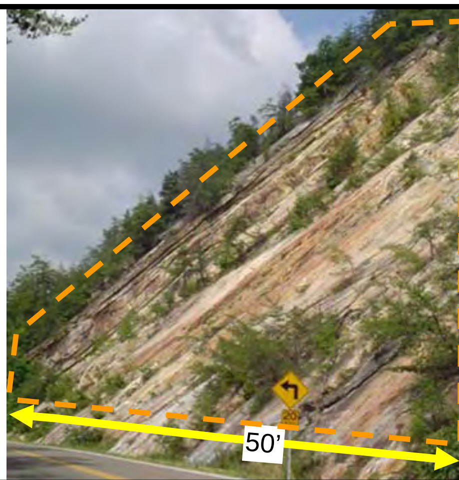
56



Failure Mode	Abundance (%)
R	>30%
P	>30%

Comments

57



Failure Mode	Abundance (%)
P	>30%

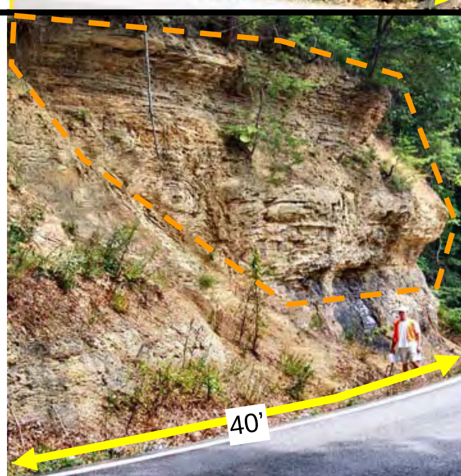
Comments

58

Failure Mode	Abundance (%)
W	>30%

Comments

59



Failure Mode	Abundance (%)
DW	>30%

Comments

60

Failure Mode	Abundance (%)
P	>30%

Comments

Appendix A: Exercise picture locations

Picture No.	County Name	Route No.	Mile Marker
17 –	Campbell,	SR009,	MM 18-40
18 –	Campbell,	SR009,	MM 00-50
19 –	Campbell,	SR297,	MM 09-75
20 –	Hawkins,	SR031,	MM 06-60
21 –	Unavailable		
22 –	Carter,	SR159,	MM 10-50
23 –	Hawkins,	SR347,	MM 08-52
24 –	Hawkins,	SR070,	MM 06-20
25 –	Claiborn,	SR063,	MM 27-30
26 –	Hancock,	SR066,	MM 07-10
27 –	Greene,	SR070,	MM 1-95
28 –	Campbell,	SR009,	MM 03-45
29 –	Unicoi,	SR036,	MM 3-80
30 –	Hancock,	SR066,	MM 01-70
31 –	Hawkins,	SR347,	MM 08-52
32 –	Hawkins,	SR347,	MM 06-38
33 –	Campbell,	SR009,	MM 10-00
34 –	Unavailable		
35 –	Hancock,	SR033,	MM 00-27
36 –	Hawkins,	SR031,	MM 04-82
37 –	Hancock,	SR033,	MM 16-75
38 –	Johnson,	SR034,	MM 08-20
39 –	Unavailable		
40 –	Campbell,	SR009,	MM 23-15
41 –	Campbell,	SR009,	MM 04-60
42 –	Campbell,	SR297,	MM 09-70
43 –	Campbell,	SR009,	MM 00-80
44 –	Campbell,	SR009,	MM 02-20
45 –	Campbell,	SR009,	MM 04-60
46 –	Campbell,	SR116,	MM 04-60
47 –	Claiborn,	SR063,	MM 21-30
48 –	Claiborn,	SR063,	MM 28-40
49 –	Unavailable		
50 –	Campbell,	I0075, (B-slope)	
51 –	Carter,	SR091,	MM 19-30
52 –	Claiborn,	SR063,	MM 36-60
53 –	Hancock,	SR033,	MM 16-70
54 –	Johnson,	SR034,	MM 7-30
55 –	Sullivan,	SR034,	MM 33-20
56 –	Campbell,	SR009,	MM 20-80
57 –	Hawkins,	SR070,	MM 16-10
58 –	Carter,	SR037,	MM 14-10
59 –	Anderson,	SR116,	MM 09-50
60 –	Carter,	SR037,	MM 15-10

Rockfall Management System for Tennessee

Appendix E:

User Manual (help file) for the Rockfall Database (Access)

December 2007

TDOT

Please note that database development continues at TDOT as this research project has become an ongoing program. For the latest information or database structure e-mail: vanessa.bateman@state.tn.us

Rockfall Database User Manual

For use with Rockfall 3.0 in Access 97 or 2000.

Purpose of Rockfall 3.0.

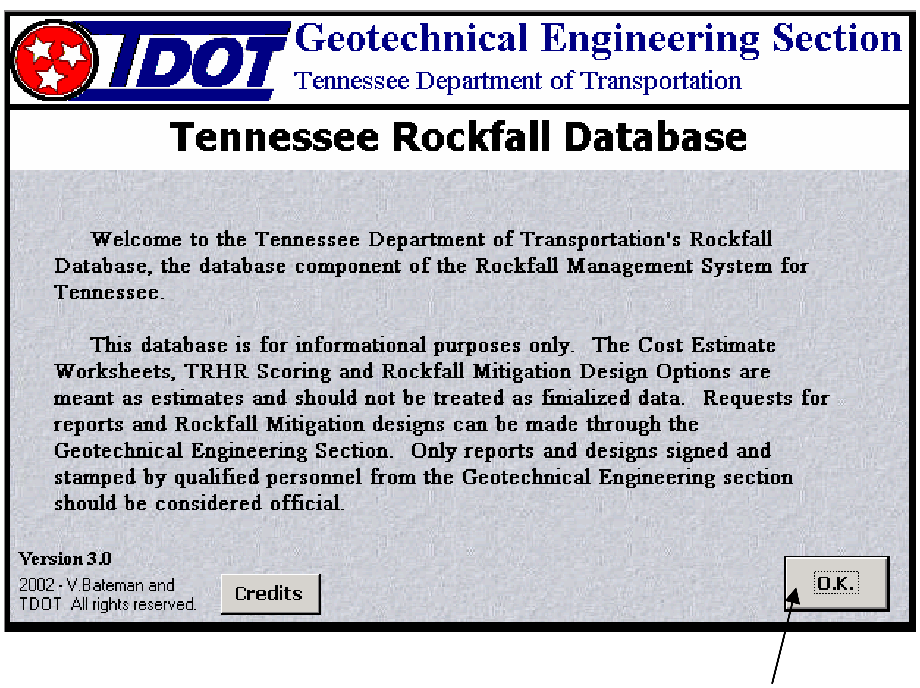
Rockfall 3.0 is a database used to store and retrieve all information about rockfall sites in a non-graphical fashion. This component of the Rockfall Management System provides access to all detailed ratings, questionnaires, pictures and other information stored within the system. It can provide details of individual sites as well as summary information about multiple sites. This component differs from the GIS component in that information is presented in forms and tables and does not employ maps to enter, view or interact with data about the rockfall sites. It uses forms and buttons as the primary user interface.

This component is provided as an interim. It is not meant to be the final implementation of the database to be included with the Rockfall Management System. However, it gives members of TDOT immediate access to all of the information that has been gathered at this time inside a program more readily familiar to its employees. The final database will be in Oracle Spatial, however, it will include a user interface similar to the one constructed for this version of the database. This interim version is provided as a functional “scale model” of the final product.

Tour of Rockfall 3.0

Start Screen

When you first open the database the start screen opens automatically. This screen gives basic information about the database and leads either to the navigations switchboard or to the credits screen.



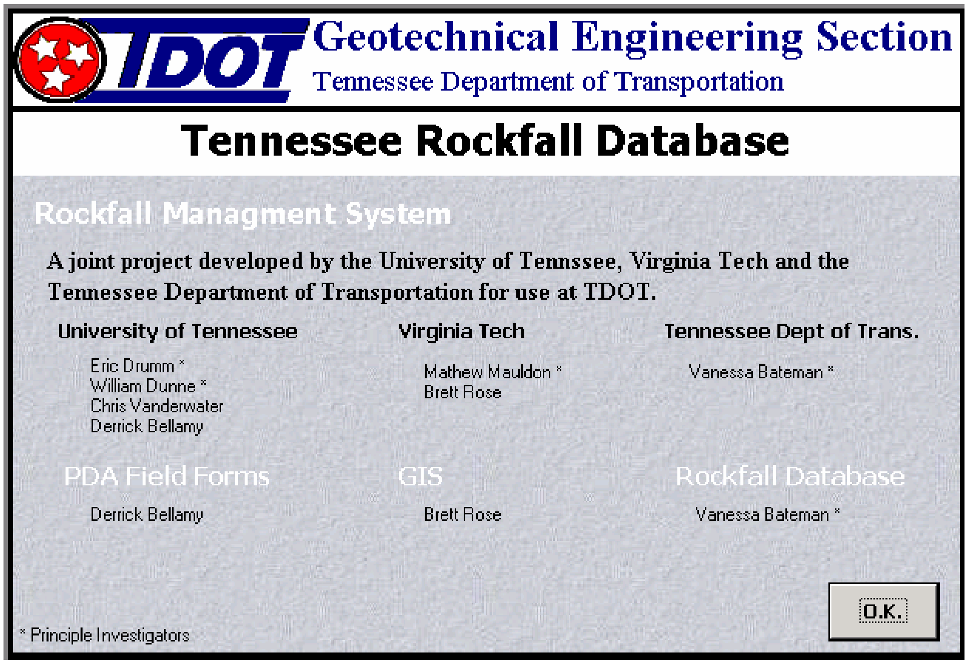
OK button

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

Clicking on the OK button will take you to the Navigation Switchboard (a form for navigating through the database. Clicking on the Credits button will take you to the credits screen.

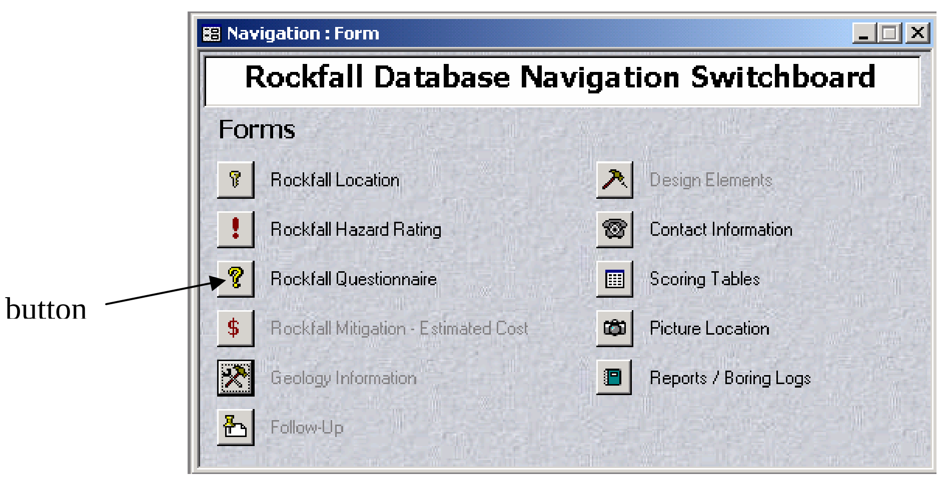
Credits Screen

This screen provides information on the people involved in the development of the Rockfall Management System including the Database, GIS, PDA forms as well as the type of information gathered to be included in the system. Clicking on the OK button will take you to the Navigation Switchboard.



Navigation Switchboard

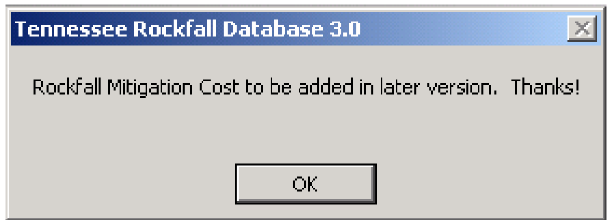
This screen gives you buttons to navigate through the database. It shows all of the different forms available for viewing. Click on any picture button to go to a form.



Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

All form names given in this manual shall be given in **bold** type. Forms whose titles are in grey type, such as the **Rockfall Mitigaiton – Estimated Cost**, **Geology Information**, **Follow-up** and **Design Elements** form are components that will be added to the system at a later date. If you click on any of these buttons you will get a message box stating that the form will be added in a later version.

For example, if you click on the **Rockfall Mitigation – Estimated Cost** button (the one with the $) you will get the following message:



Click ok to go back to the Navigation Switchboard.

The forms listed on the navigation switchboard have the following functions:

1. **Rockfall Location** – This form provides information on the location of all rockfall sites for which information is included in the database. It provides information such as highway number, log mile, reference centerline and GPS coordinates. All spatial data about a particular rockfall site is viewed within this form.
2. **Rockfall Hazard Rating** – This is the form that provides details on the Rockfall Hazard Rating performed at individual sites. When a preliminary rating has been performed, this form will only show that information. When a detailed rating has been performed, this form shows all of the details of that rating, including a final Rockfall Hazard Rating Number.
3. **Rockfall Questionnaire –** This is the form that provides access to all of the questionnaires that maintenance filled out about particular rockfall sites. These questionnaires were sent to maintenance in the late 1980's and early 1990's. They represent areas of concern from maintenance staff.
4. **Contact Information** – This form provides the name and contact information for anyone who has contributed information to the database. Maintenance staff who have filled out questionnaires, or personnel who have gone into the field to provide preliminary or detailed ratings are included.
5. **Scoring Tables** – This is a reference for the user for the Rockfall Hazard Rating system implemented within the database. A specialty Rockfall Hazard Rating was developed for the Rockfall Management System. It is an adaptation of the RHRS (recommended by the Federal Highway Administration). However, particularly in the area of geology, there are significant deviations from that system. This form provides detailed information on how to use the Rockfall Hazard

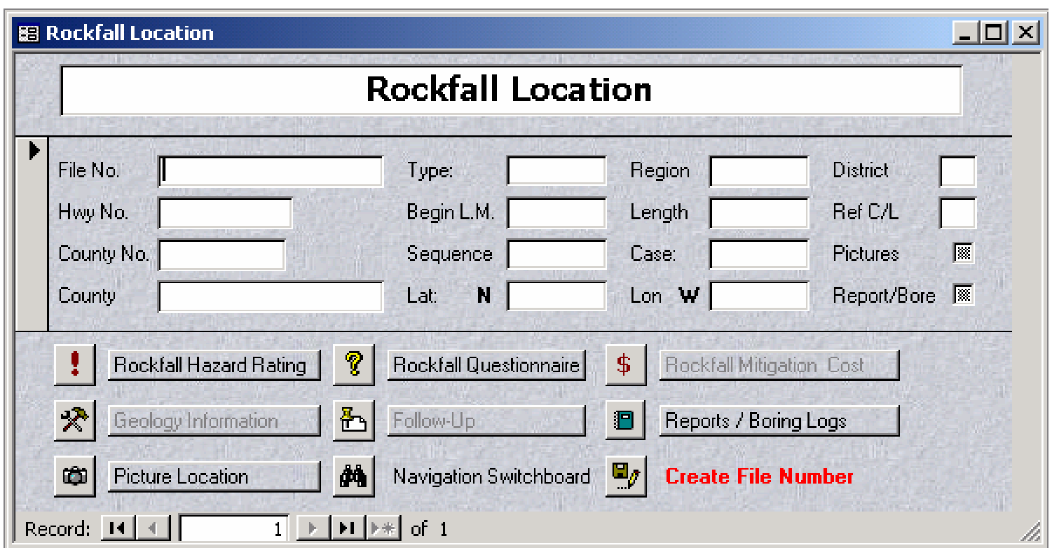
Rating provided in this database and how to arrive at a final Rockfall Hazard Number.

6. **Picture Location** – This form shows all of the pictures known to be present about a site and where these pictures are stored. This form may provide access to the pictures by hyperlink or may provide a description of where these pictures are stored.
7. **Report/Boring Logs** – This form shows all of the reports and boring logs known to be present about a site and where this information is stored. Like the picture location, this form may provide access either by hyperlink or by a description of where these reports and boring logs are stored.

Rockfall Location Form

This is the form that is central to the database. Any entry in Hazard Rating, Questionnaire, Picture Locations, Report/Boring Log Locations etc. must have an entry in the Rockfall Location form. This is where you can view (or enter) spatial information about a rockfall site. That is you can look at a description of the site location.

This form contains fields, which show the information about the specific sites. An example of a field is *File No.* or *County No.*, which would contain the file number for a give site or the county number in which the site was located. In this manual, field names shall be given in *italics*. Remember, form names are given in **bold.**



For each site, information such as site *Type*, *Highway Number*, *Begin Log mile*, *Length* of site, *Reference Centerline*, *County Number*, *Sequence* Number, *Special Case* as well as the *Latitude* and *Longitude* of the site are entered. These fields have specific formats in which data must be entered. If you try to input information that is inappropriate for a particular field, you will get an error message. For example: *County Number* must have a two digit number from 01 to 95 that correspond to the number of the county in which the site is located. Every county in Tennessee has a unique number. For example, Davidson County is 19 and Hamilton County is 33.

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

For all Rockfall Locations the *Type* entered shall be RF for rockfall sites. This has been included for future growth of the database and the incorporation of landslide information at some later date.

Sequence is the Number of times that a road has entered a county. If the road only enters a county once, the sequence number will be 0. If it has entered it twice the number will be 1 etc.

The *Special Case* is generally a letter indicating an alternate, say with 41A or 70N. This will generally not be used. If no special case is needed a 0 should be entered into this field.

The *File Number* is particularly important for the whole database. All of the information within the database is linked by this file number, without it, we would not know where the sites seen in other forms (such as the Rockfall Hazard Rating) are located. The file number is not random. It is generated from the site location data. Once you know how to read the file number, you can locate an individual site. The file number convention is as follows:

Example File Number: **33SR040O02013.25RRF**

33 = County Number
SR = State Route or Interstate (IO)
040 = Route Number
O = Special Case
02 = Sequence Number = Number of times the road enters the county. Log mile re-starts every time a road enters a county. Without a sequence number, we don't really know where a site is located.
013.25 = Log Mile at Beginning of Slope
R = Reference Centerline (left or Right)
RF = Type Code, RF for rockfalls, LA for landslides, etc.

Entering Information into the Rockfall Location Form

Some fields in the rockfall location form need to be filled in by the user and others fill in automatically. For example the following fields must have information entered:

Field Name	**Format**
Type	Must be two letters
Highway Number	SR-### or IO-### (for example SR-070)
Begin Log Mile	###.## (for example 123.33)
Length	Must be a whole number less than 10,000 Always given in feet
Reference Centerline	Must be R for right of centerline Must be L for left of centerline
County Number	## from 01 to 95, such as 19 for Davidson
Sequence	## Such as 01 for a road that enters a county twice.
Case	One letter, O if no special case.

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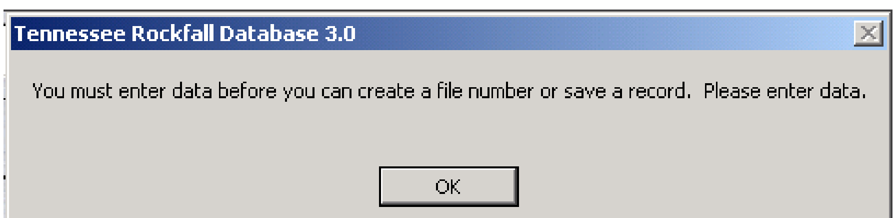
The following may or may not have information entered:

Field Name	**Format**
Latitude	In decimal degrees
Longitude	In decimal degrees
Pictures (a check box)	Click to check
Report/Bore (a check box)	Click to check

However, some fields such as *County Name*, *Region* and *District* are entered automatically when the county number is entered. The *File Number* can either be entered manually or generated using the Create File Number button.

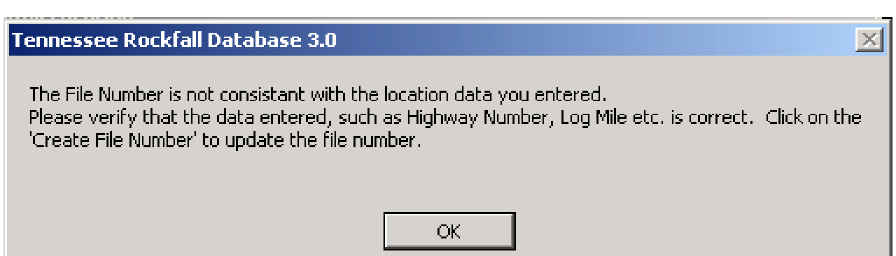
If some information is left out, you will get an error message telling you to check your information. Also, when you try to leave the form or go to another record if the file number hasn't been generated or if the file number is not consistent with the location information given you will get an error message and must fix the problem before proceeding to another form or to another record. Example error messages include:

Where there is no data entered:



Where not all of the information needed to generate a file number has been entered:

Where the file number and location data are not consistent:



Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

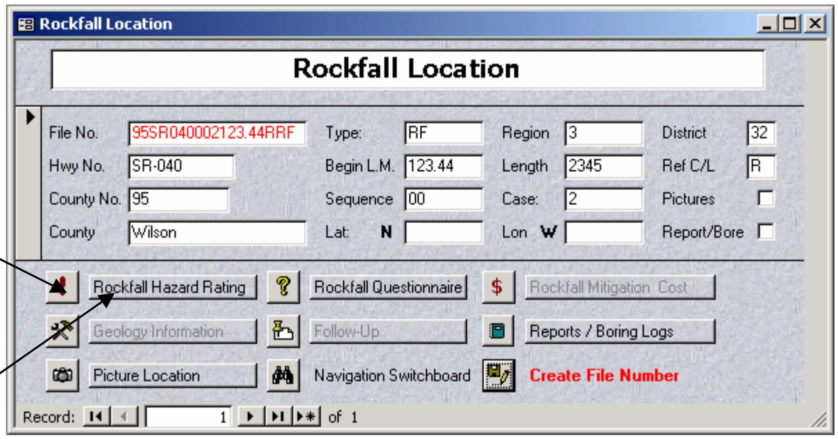
If you get this message, click ok, then look at your file number and other fields. If the location information is correct, then clicking on create file number will make sure that the file number and the location data you entered are consistent. If the location information is incorrect, then correct the information.

Navigating from the Rockfall Location Form to other Forms:

You can get to all of the other forms in the database from the **Rockfall Location** form. The buttons included at the bottom of the form will open other forms. However, there are two different types of buttons. This form establishes a button convention that is used throughout the database.

The picture buttons will take you to that individual record on another form. For example, for the following example entry in the **Rockfall Location** form:

Go to this sites record in the **Rockfall Hazard Rating** form



Go to all records on the **Rockfall Hazard Rating** Form

Suppose you want to see that sites information on the **Rockfall Hazard Rating** form. You would click the picture button (!). If you wanted to see all of the Rockfall Hazard Ratings you would click on the word button.

So, picture buttons take you to individual records on other forms, and word buttons take you to the first record on the form.

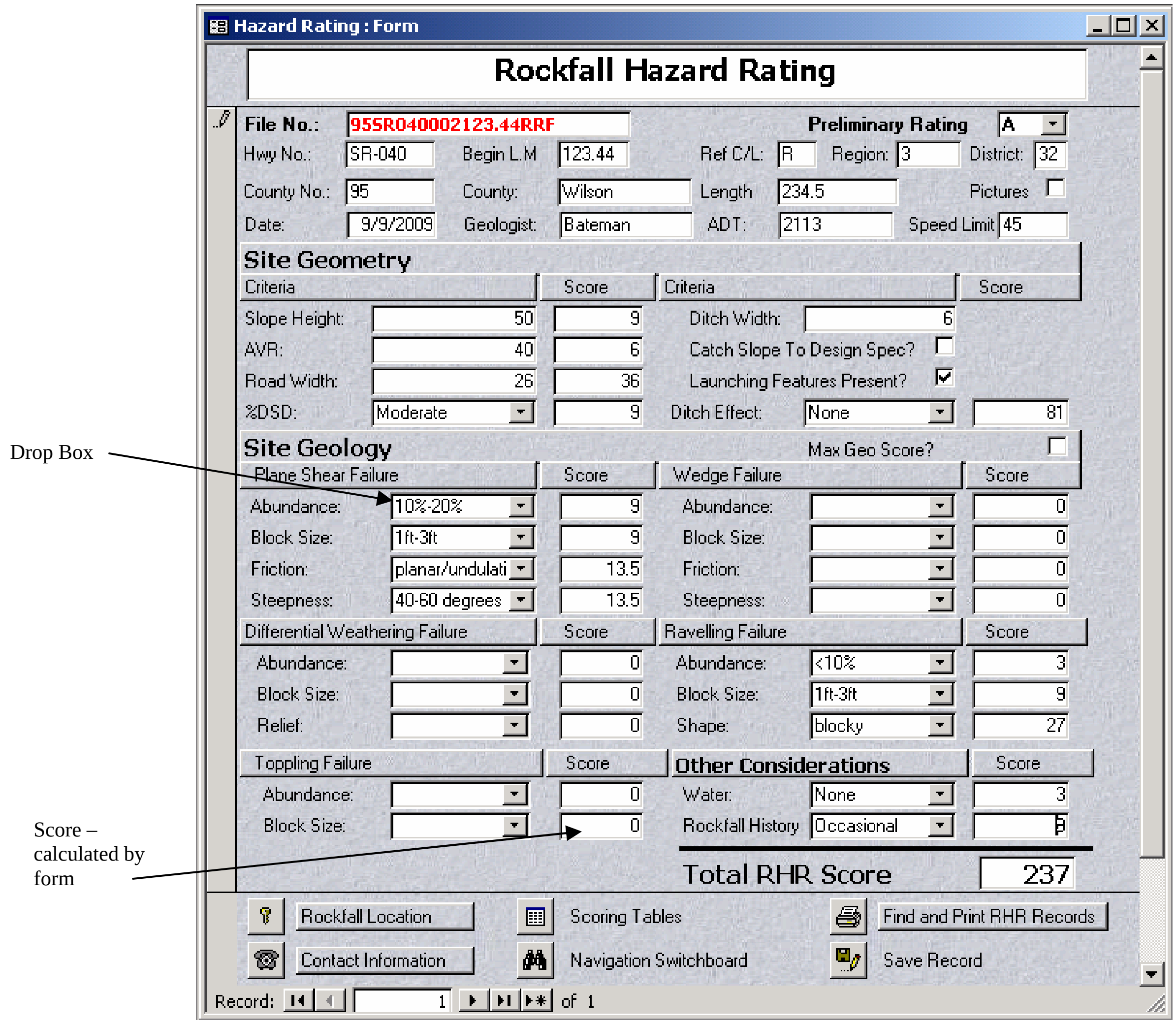
As with the **Navigation Switchboard**, some of the forms are not yet active and will be added in a later version. These buttons are those whose titles appear in grey. Clicking on one of these will bring up a message box that tells you this form will be added later.

For any of the forms that follow there will always be a button for the Navigation Switchboard. That button has the picture of a pair of binoculars.

Hazard Rating Form

This form has a record entry for every site where there is rockfall hazard information. This includes both the Preliminary Rating and the detailed rating.

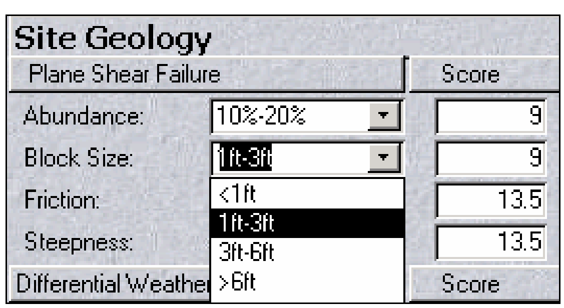
Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.



Please see Appendix ?? or the Scoring Tables form for details on how to fill out a detailed hazard rating.

Once the file number has been entered for a specific site, the location information appears on the form and does not need to be entered by the user.

Now this form uses a lot of drop boxes, which provide all of the alternatives that can be chosen for a particular field. For example, lets look at Block Size under Plane Shear:



Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

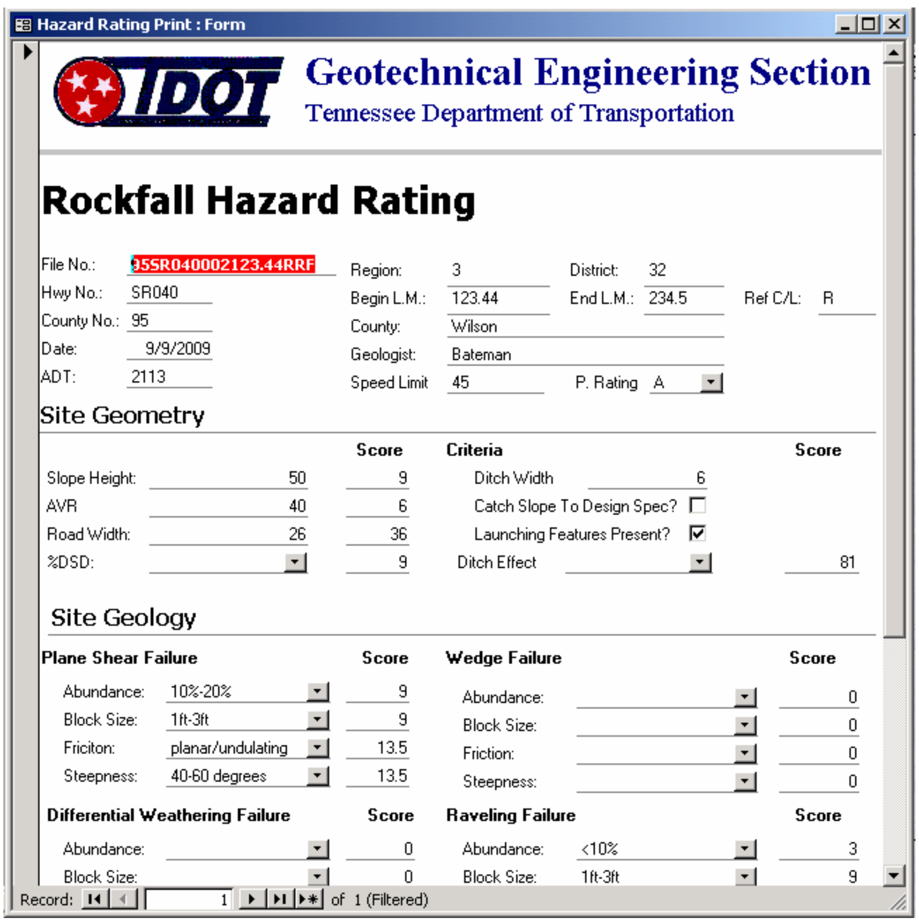
Note that this has 4 choices, <1 ft, 1ft–3ft, 3ft-6ft or >6ft. This field can also be blank. Once data is entered for this or any other scored field, the form automatically calculates the score. In this case, with a block size of 1ft-3ft the score is 9. The RHR Score at the bottom (in this case 237) is also calculated automatically by the form.

Navigating from the Rockfall Location Form to other Forms:

Like the **Rockfall Location** form, some navigation buttons are made available at the very bottom of the form. However, several new buttons have been added. The save record button will save the record. The record will automatically be saved once you go to another record, or try to close the form. However, should you wish to save while you are still working with one record, this button will allow you to do so.

The Find and Print RHR Records buttons lead to a printable form. The form shown above is not set up for printing, however, this same information can be viewed and modified on a form meant for printout.

If you click on the printer button you will be taken to that individual records printable Hazard Rating Form. If you want to see all of the Hazard Rating records, click the word button. Below you can see an example of the printable form:



When printed, this form will printout individual records on one single page.

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Geotechnical Engineering Section
Tennessee Department of Transportation

Rockfall Hazard Rating

File No.:	95SR040002123.44RRF	Region:	3	District:	32		
Hwy No.:	SR040	Begin L.M.:	123.44	End L.M.:	234.5	Ref C/L:	R
County No.:	95	County:	Wilson				
Date:	9/9/2009	Geologist:	Bateman				
ADT:	2113	Speed Limit	45	P. Rating	A		

Site Geometry

		Score	Criteria		Score
Slope Height:	50	9	Ditch Width:	6	
AVR	40	6	Catch Slope To Design Spec?	☐	
Road Width:	26	36	Launching Features Present?	☑	
%DSD:		9	Ditch Effect		81

Site Geology

Plane Shear Failure		Score	Wedge Failure		Score
Abundance:	10%-20%	9	Abundance:		0
Block Size:	1ft-3ft	9	Block Size:		0
Friciton:	planar/undulating	13.5	Friction:		0
Steepness:	40-60 degrees	13.5	Steepness:		0
Differential Weathering Failure		**Score**	**Raveling Failure**		**Score**
Abundance:		0	Abundance:	<10%	3
Block Size:		0	Block Size:	1ft-3ft	9
Relief:		0	Shape:	blocky	27
Toppling Failure		**Score**	**Other Considerations**		**Score**
Abundance:		0	Water:	None	3
Block Size:		0	Rockfall History	Occasional	9

Total RHR Score **237**

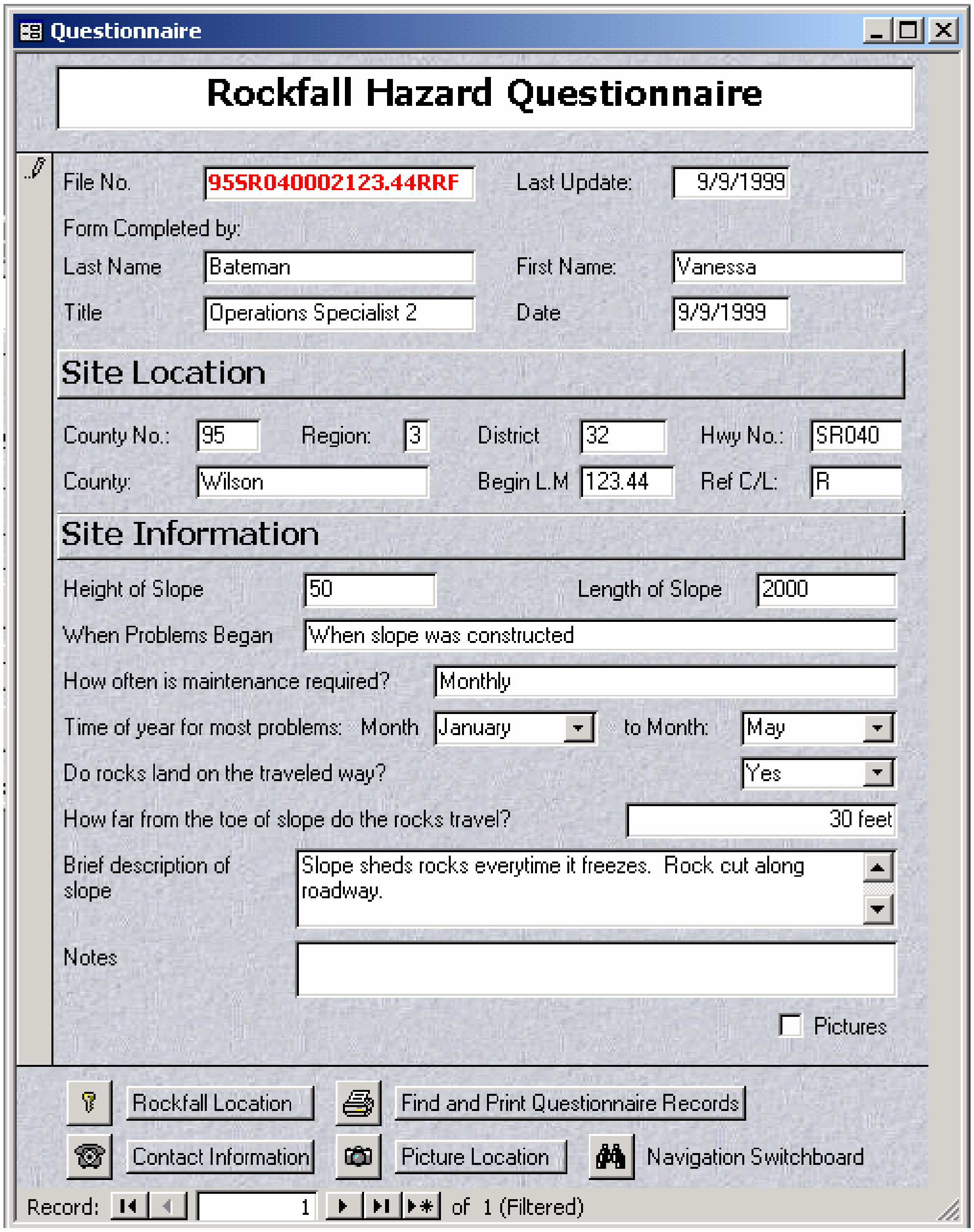
Comments

Monday, September 09, 2002 *Page 1 of 1*

Questionnaire Form

This form gives information about a particular site from paper questionnaires sent to Maintenance in the late 1980's and inconsistently updated in the 1990's.

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.



As with the Hazard Rating form you can navigate to other forms using the buttons at the bottom. Again, the picture buttons take you to that record on other forms and the word buttons take you to all of the records. The Find and Print Questionnaire Records button operate just like those on the Hazard From. The printer picture will take you to an individual questionnaire record formatted for printing and the word button takes you to all of the records in printable form. Below you can see an example of this one page printout of our example record.

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

Geotechnical Engineering Section
Tennessee Department of Transportation

Rockfall Hazard Questionnaire

File No. **95SR040002123.44RRF**

Form Completed by:

Last Name: Bateman | First Name: Vanessa

Title: Operations Specialist 2 | Date: 9/9/1999

Site Location

County No.: 95 | Region: 3 | District: 32 | Hwy No.: SR040

County: Wilson | Begin L.M.: 123.44 | Ref C/L: R

Site Information

Height of Slope: 50 | Length of Slope: 2000

When Problems Began: When slope was constructed

How often is maintenance required? Monthly

Time of year for most problems: Month: January | to Month: May

Do rocks land on the traveled way? Yes

How far from the toe of slope do the rocks travel? 30 feet

Brief description of slope

Slope sheds rocks everytime it freezes. Rock cut along roadway.

Notes

Last Update: 9/9/1999

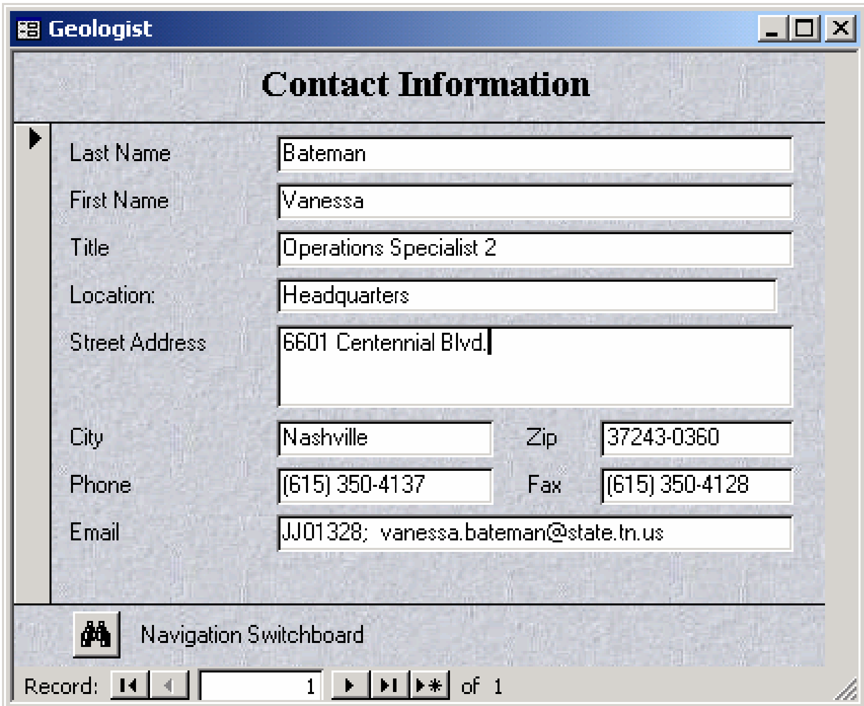
☐ Pictures

Tuesday, May 14, 2002 *Page 1 of 1*

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

Contact Information Form

This form provides the name and contact information for anyone who has contributed information to the database. Maintenance staff who have filled out questionnaires, or personnel who have gone into the field to provide preliminary or detailed ratings are included. As with other forms, it includes a navigation button at the bottom.

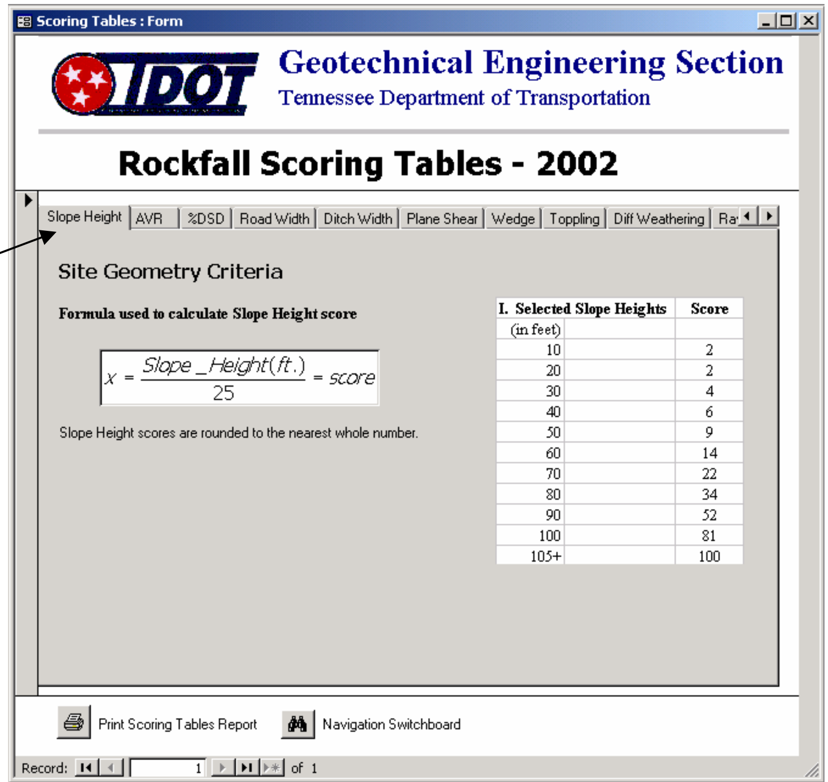


Scoring Tables Form

This form shows the details of how to score the Rockfall Hazard Rating included with the Rockfall Management System and seen on the Hazard Rating form. Now, the form will calculate all of this, but the scoring tables form is provided as a reference either to do some scoring by hand, or to see how the program calculates the score.

Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

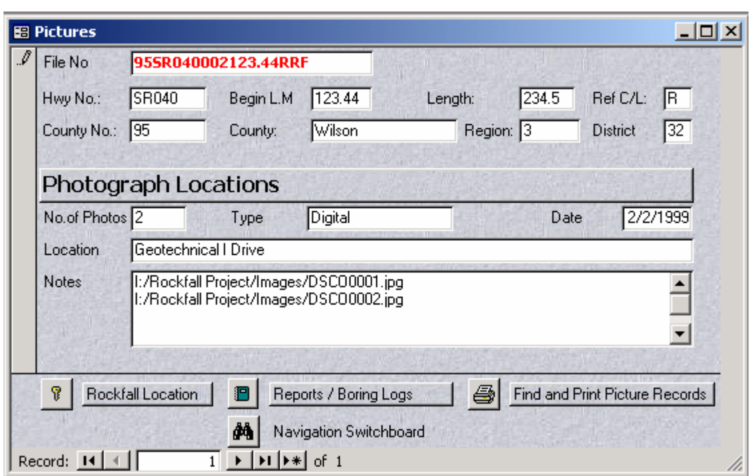
tabs



Clicking on the tabs (such as Slope Height or AVR) will bring up an individual "card" which shows how each score is calculated. Formulae and tables used are shown. You can print out a report (formatted for printing) by clicking on the printer button. As always, you can get back to the navigation switchboard by clicking on the picture of the binoculars.

Picture Location Form

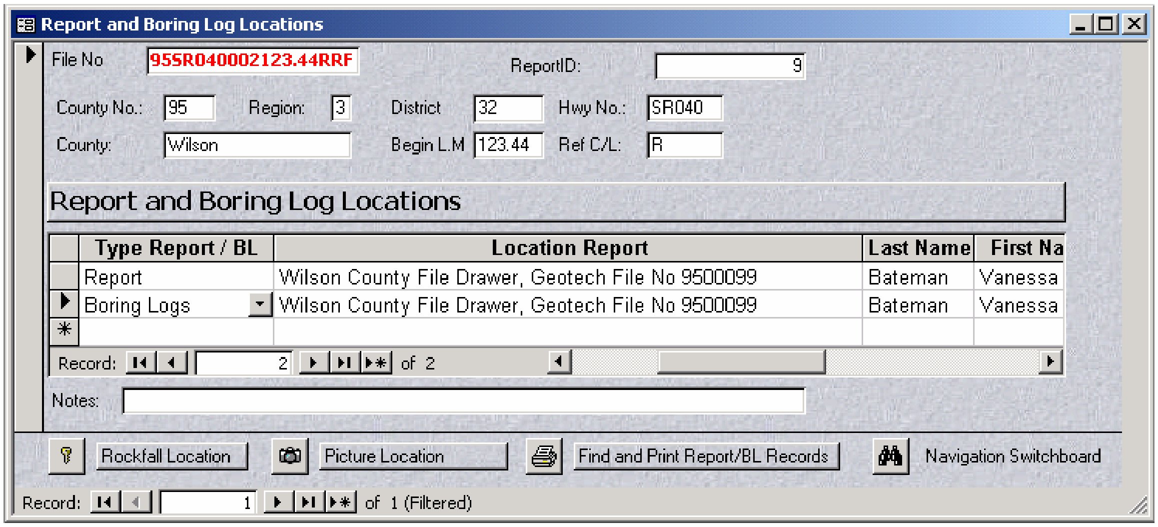
This form shows all of the pictures known to be present about a site and where these pictures are stored. This form may provide access to the pictures by hyperlink or may provide a description of where these pictures are stored.



Note all rockfall data shown in this manual is not real. It is made up purely to provide an example to the user.

Navigation buttons are included at the bottom of the form. Like the **Hazard Rating** form and the **Questionnaire** form, there are buttons for a printable form. The printer picture button will take you to the individual record on a printable form and the Find and Print Picture Records will show all of the records on printable forms.

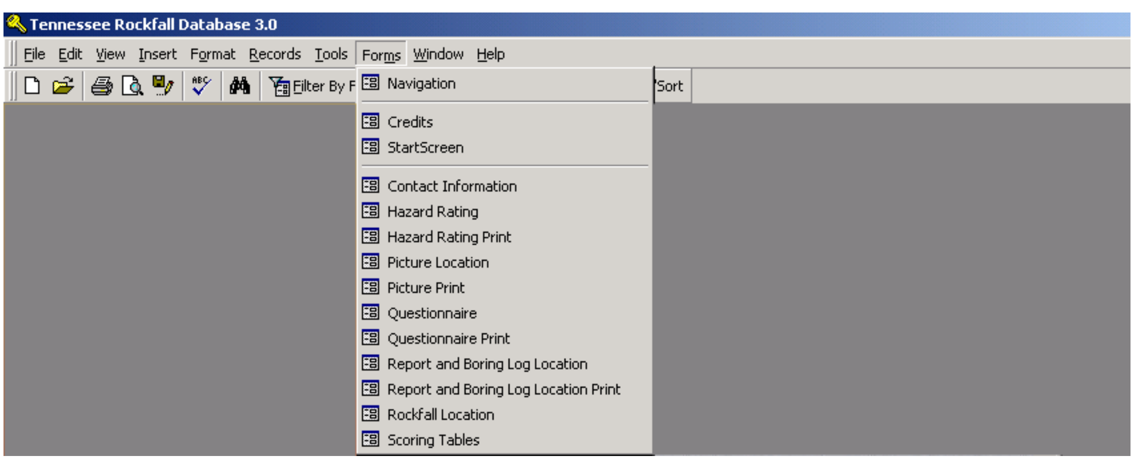
Report/Boring Log Location form



Navigation buttons are included at the bottom of the form. Like the **Hazard Rating** form and the **Questionnaire** form, there are buttons for a printable form. The printer picture button will take you to the individual record on a printable form and the Find and Print Report/BL Records will show all of the records on printable forms.

Custom Menus

The Rockfall Database has some custom menus that can be used for navigation.



Choosing any one of these forms under the forms menu will bring up that form.

Rockfall Management System for Tennessee

Appendix F:

GIS Implementation and User Manual

December 2007

TDOT

Please note that GIS development continues at TDOT as this research project has become an ongoing program.
For the latest information or GIS structure e-mail: vanessa.bateman@state.tn.us

GIS Implementation of Rockfall Management System

The rock cut data gathered during the Phase I implementation of the Tennessee Rockfall Management System (RMS) may be divided into two categories: attribute and location information. The attribute data comprises all the information collected at each rock cut site that was used to compute the detailed hazard rating as described in Appendix A. The location information was recorded as a log mile reference for each site. In addition, the latitude and longitude were recorded using a GPS receiver for a few sites. GPS coordinates were not collected at every site because of inadequate line of site with the satellite system due to narrow valleys and overcast days, as well as equipment limitations with the PDA GPS receivers used on the project. This equipment limitation should be alleviated as PDA-compatible GPS equipment improves.

Log mile references for each site were used to obtain location coordinates from the GIS interface via a customized script. The script reads the log mile location information for each record in the database, finds that point along the state route network layer within the GIS and then records the coordinates in the database table. The point locations of each rated rock cut were located along a linearly referenced network matching the one used in TRIMS. Coordinates for each site were recorded in the database table as latitude, longitude (decimal degrees) and east, north (feet) so that the points may be mapped in either geographic or projected (state plane) systems.

The database table was converted into an Access database with the additional spatial information needed to map rock cut locations within GeoMedia. Access databases that contain the necessary tables for mapping as a layer in GeoMedia are known as Access Warehouses contain the following tables.

- *AttributeProperties** contains metadata about each non-spatial field in the database. The metadata provides details about the data in each attribute field.
- *FieldLookup** holds a list of all the fields in the feature tables.
- *GAliasTable** provides a cross reference between the metadata table types and their corresponding names.
- *GCoordSystem** stores information about the projection, datum and other geographic parameters.
- *GeometryProperties** contains the spatial data used for mapping.
- *GFeatures** holds a list of all the feature tables maintained in the warehouse.
- *GSQLOperatorTable** contains a list of operators which may be used in performing different calculations and queries on the feature data.
- *ModificationLog** is used to keep track of database transactions such as insert, delete and update. This table is cleared each time the database is closed.
- *ModifiedTables** holds a list of tables that have been modified.
- *Phase_I_Sp* is a *feature table*. This table contains all the attribute data for each record in the database along with its geometry information.

* These are GeoMedia Pro proprietary tables, which should NOT be modified by users within Access or GeoMedia unless the user has extensive experience with GeoMedia Access warehouses.

The Phase_I_Sp feature table holds all the information gathered during the detailed rating of the rock cuts. Tables F-1a and F-1b provide the list of the fields used in the feature table and their brief description. More detailed descriptions are provided in the previous appendices. The “Sp” in the name of the feature table is meant to indicate that the geographic information is projected in the 1927 Tennessee State Plane coordinate system using North American Datum 1927 (NAD27) and Clarke 1866 ellipsoid. The other layers used in the GIS are the linear state route network; county, regional and district boundaries; city and township locations. These layers are provided as ArcView ShapeFiles on the accompanying CD-ROM.

The information in the RMS may be modified and new records added within the GeoMedia Professional 4.0 GIS interface, as long as the user connects to the Access warehouse with read/write permission. The process of viewing and modifying the RMS within GeoMedia is described in the next section, “RMS in the GeoMedia Workspace.”

Table F – 1a. Database field description

Field name	Description
DATE	Date
REFF_NO	Reference file number
PRELM_R	Preliminary rating
COUNTY	County
CNTY_NO	County number
DISTRCT	District
REGION	Region
RT_NUM	Route number
SQNC	Sequence number
LOG_M	Log Mile
R_CL	Reference to the centerline
RATER	Raters name
SPEEDL	Speed limit
ADT	Average Daily Traffic
ALHA	Alpha angle used in slope height calculation
BETA	Beta angle used in slope height calculation
SLP_HT	Calculated slope height in feet
SHT_SC	Slope height score
RD_WDTH	Roadway width in feet
W_SC	Road width score
DSD	AASHTO Decision Sight Distance (FT)
ACT_DSD	ACTUAL DSD (ft)
P_DSD	Percent actual DSD to AASHTO DSD
RDSD	Rated %DSD
DSD_SC	%DSD score
SLP_L	Slope Length in feet
AVR_PC	Percent of Average Vehicle Risk
AVR_SC	AVR score
CATCH	Effective catchment width in feet
6_1CATCH	6:1 catchment (YES/NO)
LAUNCH	Launching features (YES/NO)
DITCH	Percent of ditch effectiveness
DCHEFF_SC	Ditch effectiveness score
WATER	Water rating
WTR_SC	Water score
R_HIST	Rockfall history
HIST_SC	Rockfall History score
RHRS	RHRS Total Detailed Score
LAT	Latitude (decimal degrees)
LONG	Longitude (decimal degrees)
EAST_FT	East state plane feet
NORTH_FT	North state plane feet

Table F-1b. Geologic rating database field description

Field Name	Description		
P_A	Abundance	Planar Failure	Geologic Characteristics Case 1: Structural
P_BS	Block size (ft)		
P_S	Steepness (degrees)		
P_F	Friction		
PL_SC	Table Planar Score		
W_A	Abundance	Wedge Failure	
W_BS	Block size (ft)		
W_S	Steepness (degrees)		
W_F	Friction		
WD_SC	Table Wedge Score		
T_A	Abundance	Topple Failure	
T_BS	Block Size		
TP_SC	Table Topple score		
DW_A	Abundance	Differential Weathering	Geologic Characteristics Case 2: Weathering Related
DW_BS	Block size (ft)		
DW_R	Relief (ft)		
DW_SC	Table Differential Weathering score		
R_A	Abundance	Raveling	
R_BS	Block size (ft)		
R_R	Relief (ft)		
R_SC	Table Raveling score		

RMS in the GeoMedia Workspace

The Rockfall Management System may be easily viewed and edited through the GeoMedia GIS interface. This section will provide step-by-step instruction for viewing and making some minor edits to the RMS via GeoMedia.

Requirements:

- A working knowledge of GeoMedia Professional 4.0 (Intergraph).
- Windows PC with GeoMedia Professional 4.0.
- GIS data layers provided with this report on the accompanying CD-ROM in the directory labeled .../Phase_I_GIS.

A GeoMedia workspace (GeoWorkspace) is a file used to access geographic data via connections made to geographic data warehouses. Warehouses are any data source such as an Access database, ArcView ShapeFile, ARC/INFO coverage, Oracle or MGE files which contain geographic references for each record. Connections to warehouses may be made as read only or with read/write capability. ESRI warehouses (ArcView and ARC/INFO) are restricted to read-only access.

GeoMedia Pro can edit both geometry and attribute data for warehouses with read/write connections. GeoMedia connects to warehouses by being pointed to a directory that contains a collection of the indicated geographic database type (ArcView ShapeFile, ARC/INFO coverage, Oracle or MGE). The directory must only have one database type within it.

Tutorial – Setting up the GeoWorkspace

This tutorial will illustrate the following procedures:

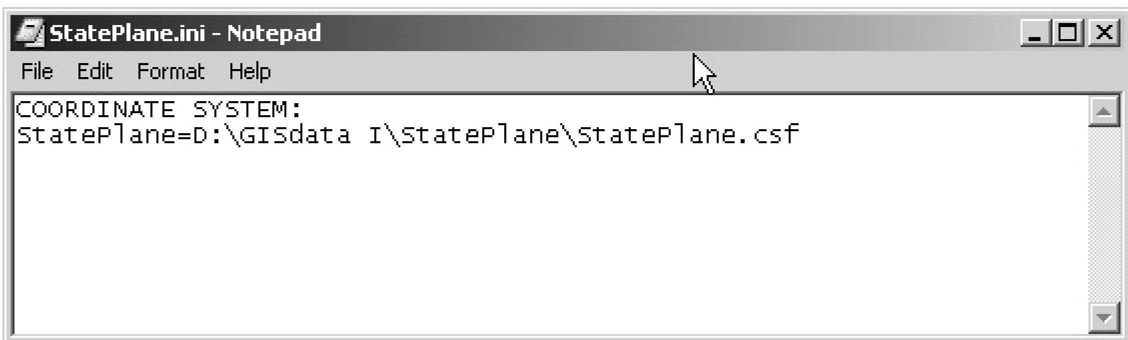
- Creating a Geo Workspace
- Making connections to Access and Arc View warehouses
- Creating a base map, including county boundaries and state routes
- Viewing and editing the RMS data
- Creating a thematic map of the rated rock cuts
- Viewing the thematic map

Preliminary Tasks for Setting up the Tutorial

1. To begin with, copy the "Phase_I_GIS" folder from the CD-ROM to a location where the data can be accessed and changed if needed. This file contains the different data layers that will be used to produce the maps in this tutorial.

2. Locate the StatePlane.ini file and the …\Phase_I_GIS\Shape_Files\StatePlane directory. The .ini file directs GeoMedia to the coordinate definition file which contains information about the coordinate system used by the geographic data files. The path to the coordinate system file will be different on different machines, requiring the StatePlane.ini file to be edited. The .ini file can be edited in any text editor such as Notepad.

3. Open the StatePlane.ini file in Notepad or any other text editor. The file should have only 2 lines of text:
   COORDINATE SYSTEM:
   StatePlane=D:\GISdata I\StatePlane\StatePlane.csf



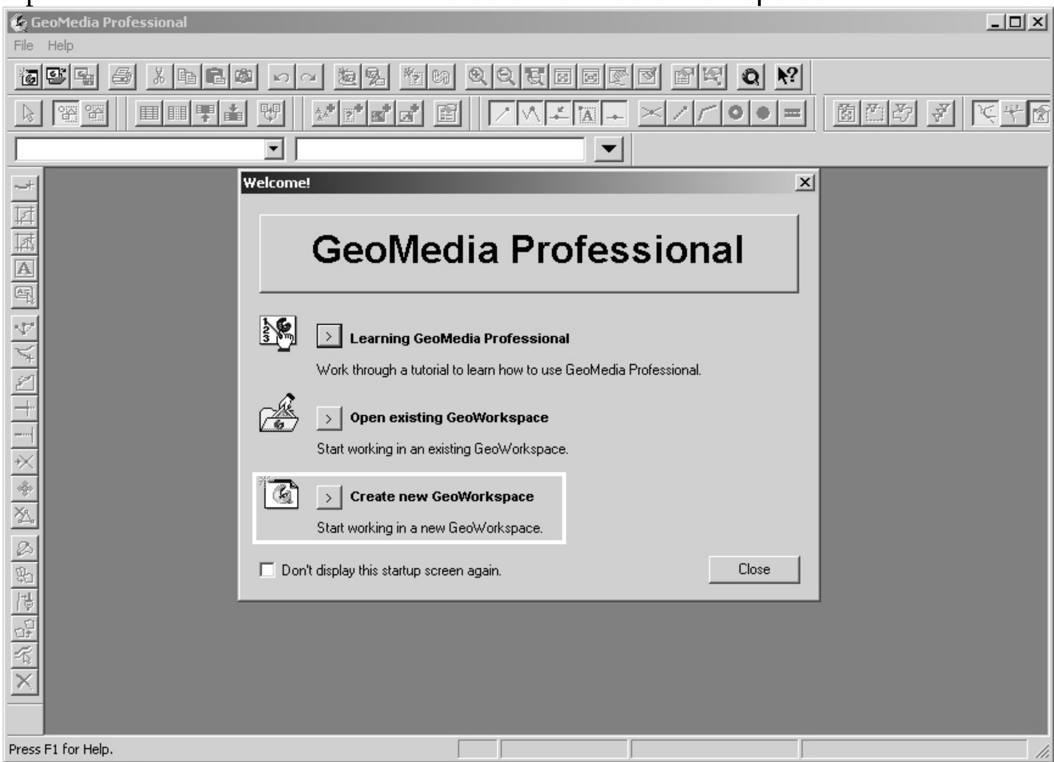
4. Change the path from D:\GISdata I\StatePlane\StatePlane.csf to *YourDrive&Path*\Phase_I_GIS\Shape_Files\StatePlane, where *YourDrive&Path* represents the path to the drive and folder to which the "Phase_I_GIS" folder was copied.

5. Save the file and close Notepad.

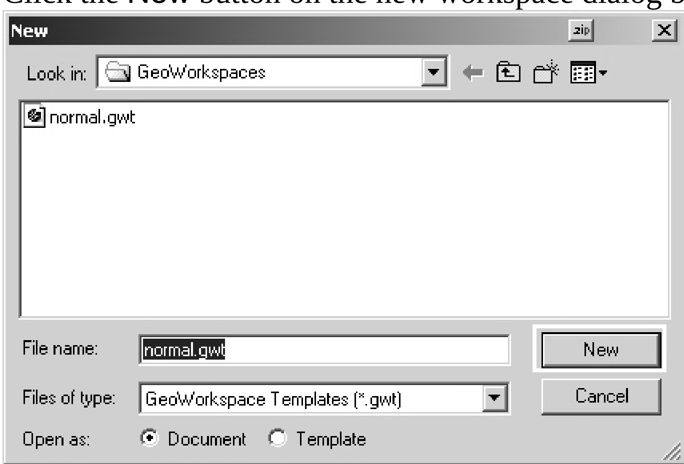
Now all the files are ready to begin the tutorial.

Step-by-Step Instructions for Interacting with the Geomedia Workspace

1. Open GeoMedia Pro and click on create new GeoWorkspace

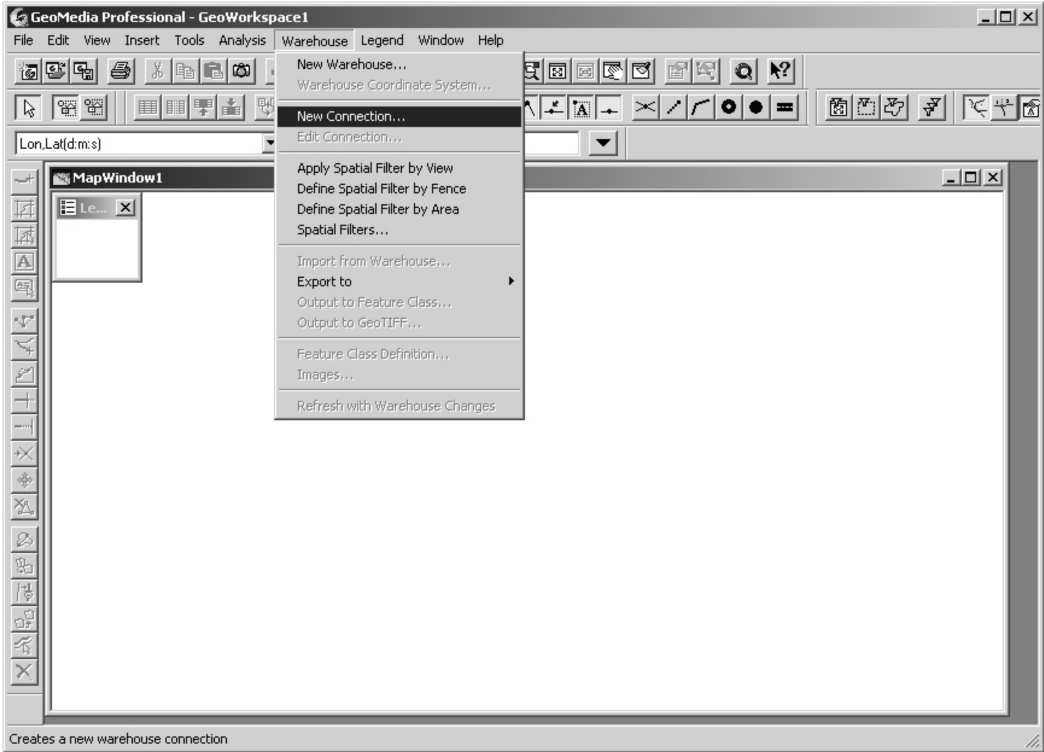


2. Click the New button on the new workspace dialog box.



Now the new GeoWorkspace is open and data connections can be made to the Access and ArcView warehouses.

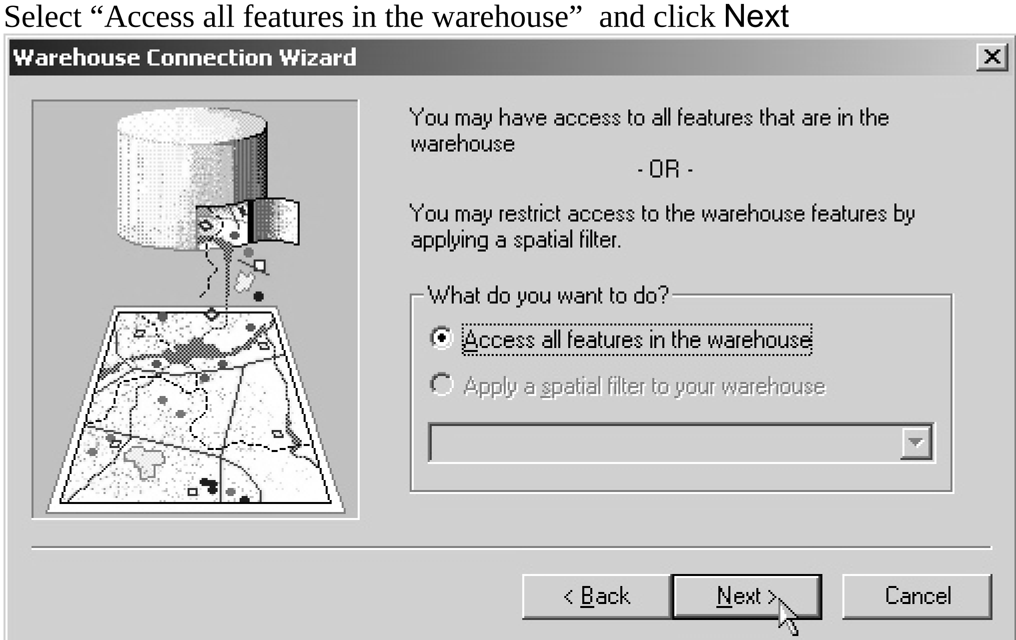
3. Click on the warehouse menu and then click New connection



The Warehouse Connection Wizard starts and the first thing that needs to be done is to select the type of warehouse to connect to. Select Access and click Next.

Name the connection (for example, Access Connection 1) and provide a description (example: Phase 1 RHRS), then click Browse… to locate the warehouses. In the open file dialog box, navigate to the directory where you copied the Phase_I_GIS\Shape_Files\AccessWH\PhaseI.mdb file and then click Open and then Next in the Wizard dialog box.

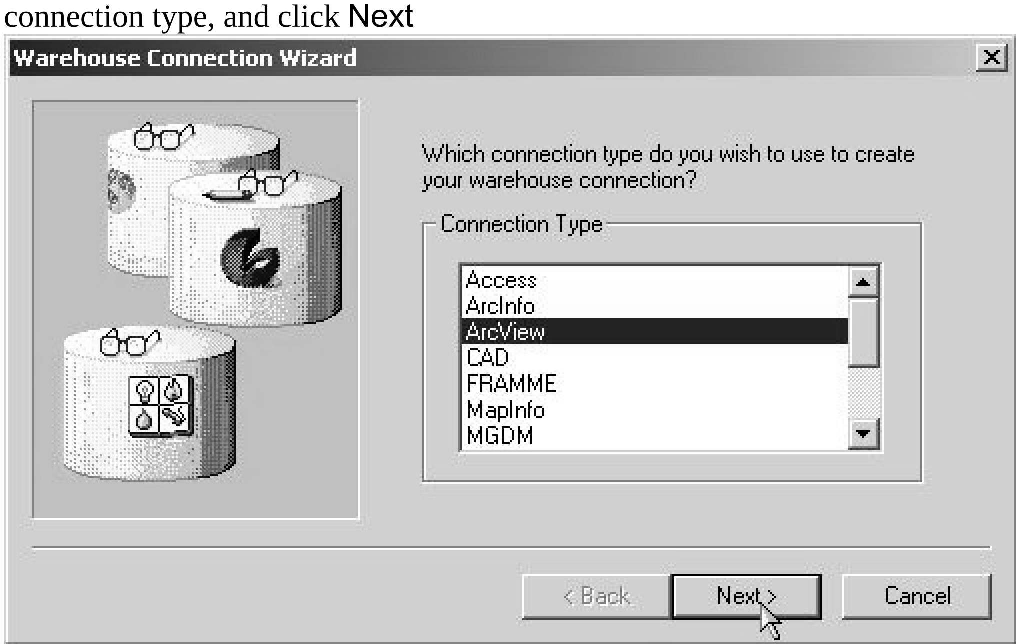
Select "Access all features in the warehouse" and click Next



in the next dialog box select "Let the wizard open the connection as read/write" and click Finish.

The connection has been made to the Phase I Access data warehouse.

4. Repeat the procedure described in step 3, however this time select ArcView as the connection type, and click Next

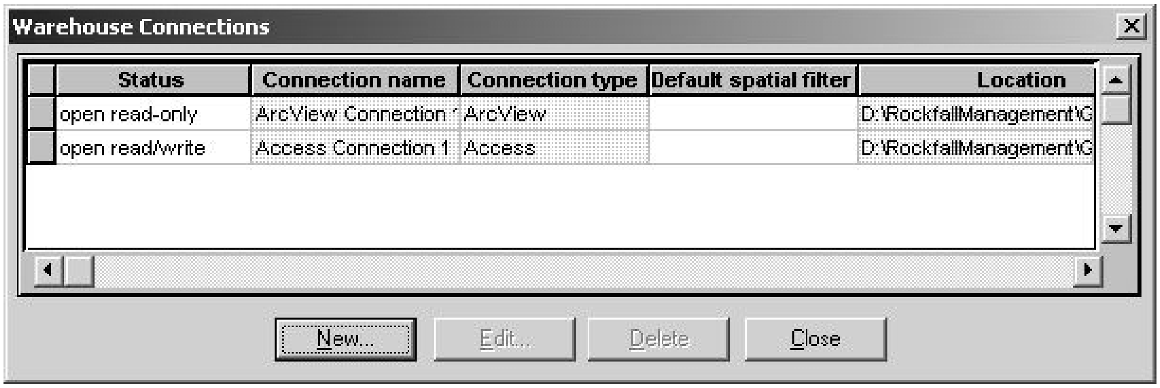


On the next dialog box browse to the location of the shape files that are in the Phase_I_GIS\Shape_Files\StatePlane folder and click Next.

Select the option "Access all features in the warehouse" and click Next

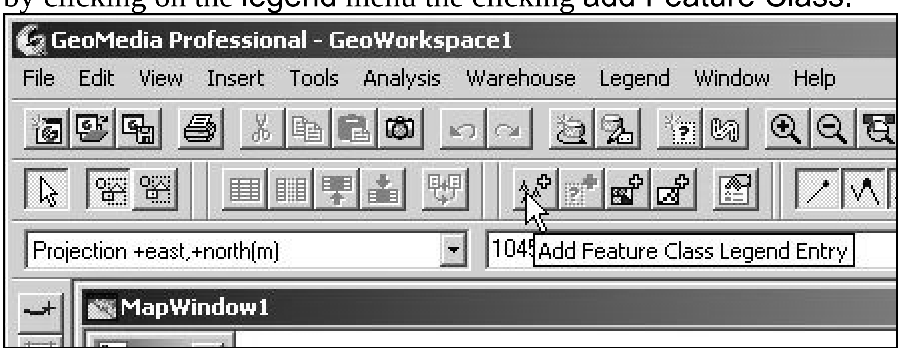
Let the wizard open the warehouse as read-only and click Finish.

5. All the connections needed to make maps of the rated counties have now been made. Verify the connections by clicking the menu warehouse – edit connection. The following dialog box should come up and show a list of the current warehouse connections.

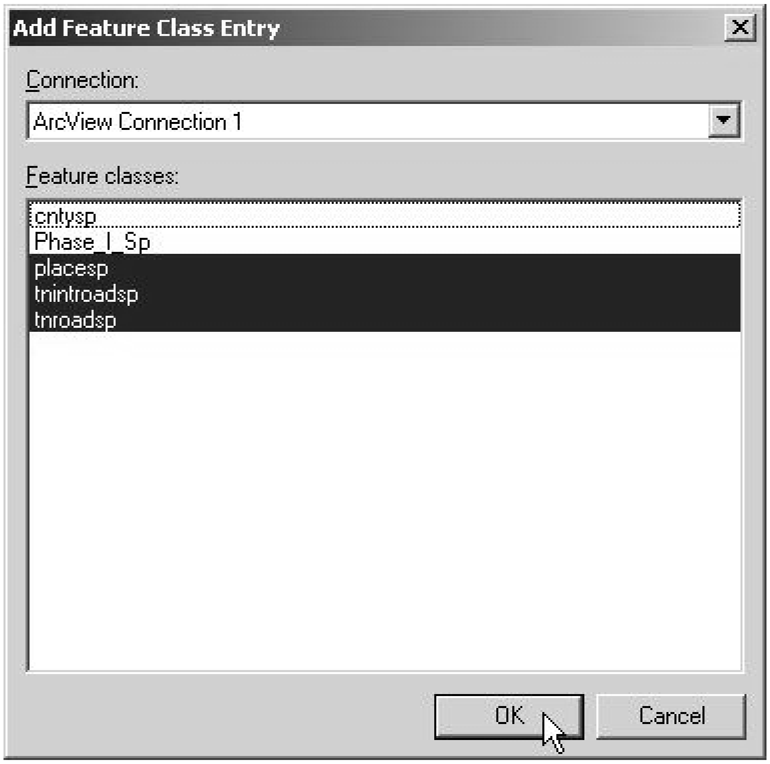


One Access connection with read/write status and one ArcView connection with read-only status should be open. If there was a problem opening the ArcView warehouse, make sure the correct changes have been made to the StatePlane.ini file as explained at the beginning of this tutorial.

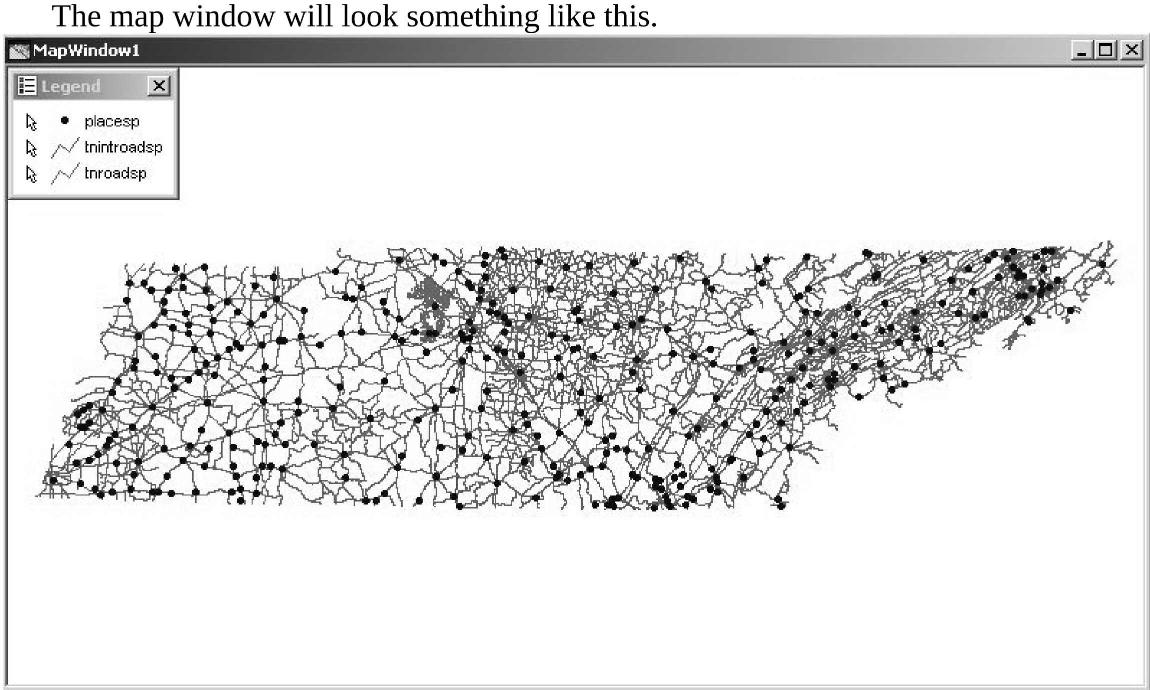
6. Now the connections will be used to add features to the map window. Click on the add Feature Class Legend Entry button on the tool bar. Feature classes may also be added by clicking on the legend menu the clicking add Feature Class.



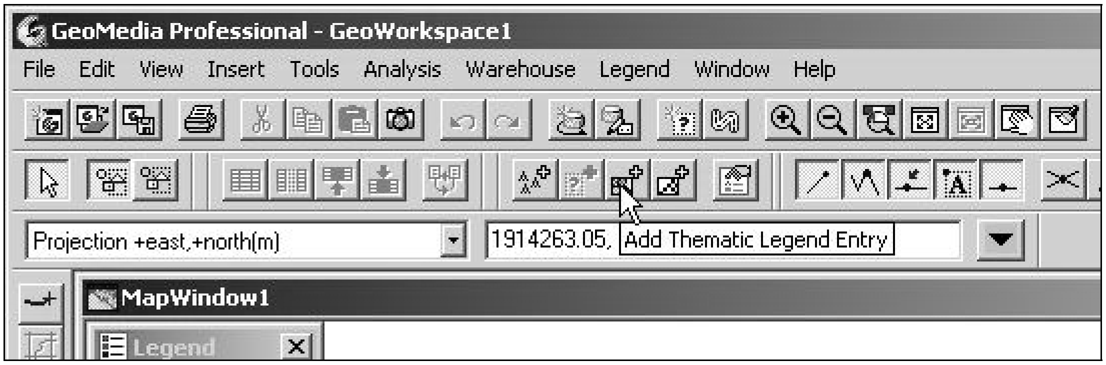
7. The Add Feature Class Legend Entry dialog box comes up. Select the ArcView connection. Now a list of the feature classes found in that connection appears. Holding down the control key (Ctrl) click on the feature classes named placesp, tnintroadsp, and tnroadsp. These are the cities, interstates and TRIMS roads. The new features will be added to the map window. The appearance of the features in the map window can be changed by double clicking the legend entries and then clicking the Style button in the Legend Properties dialog box.



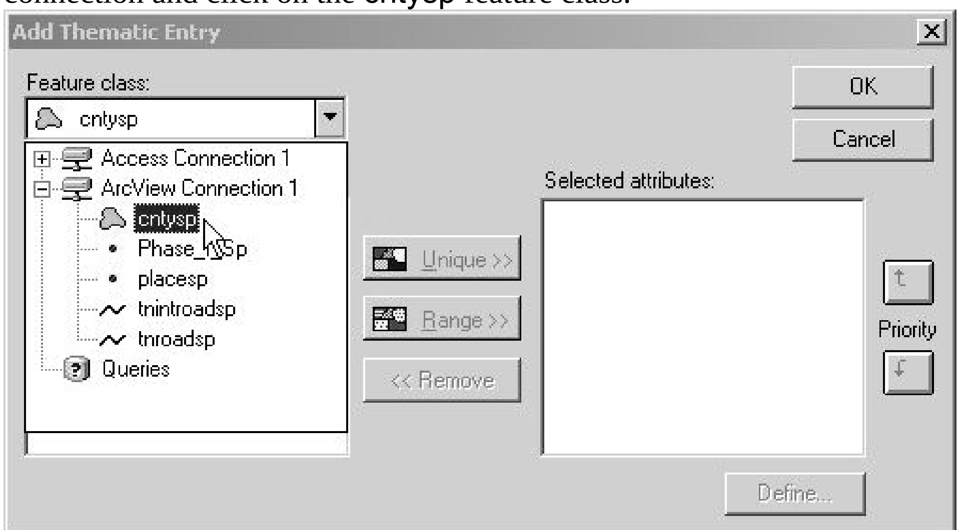
The map window will look something like this.



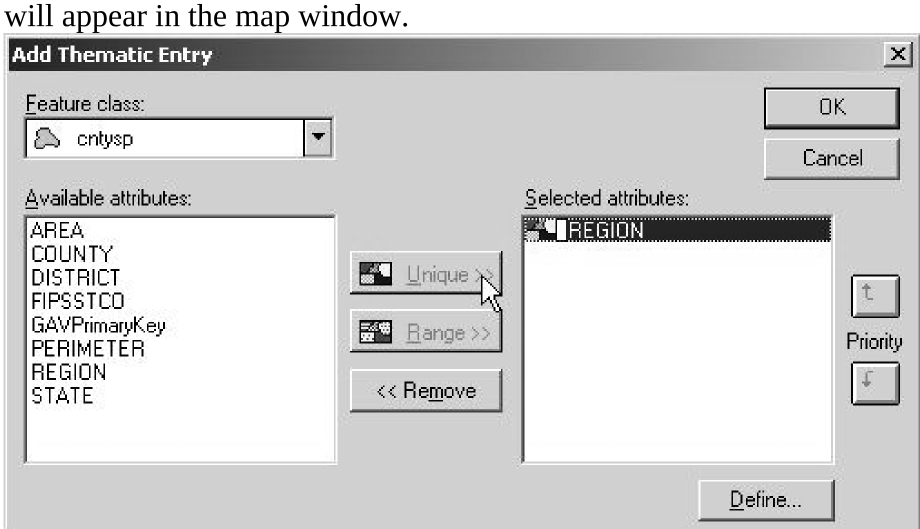
8. Now click on the **Add Thematic Legend Entry** button on the tool bar.



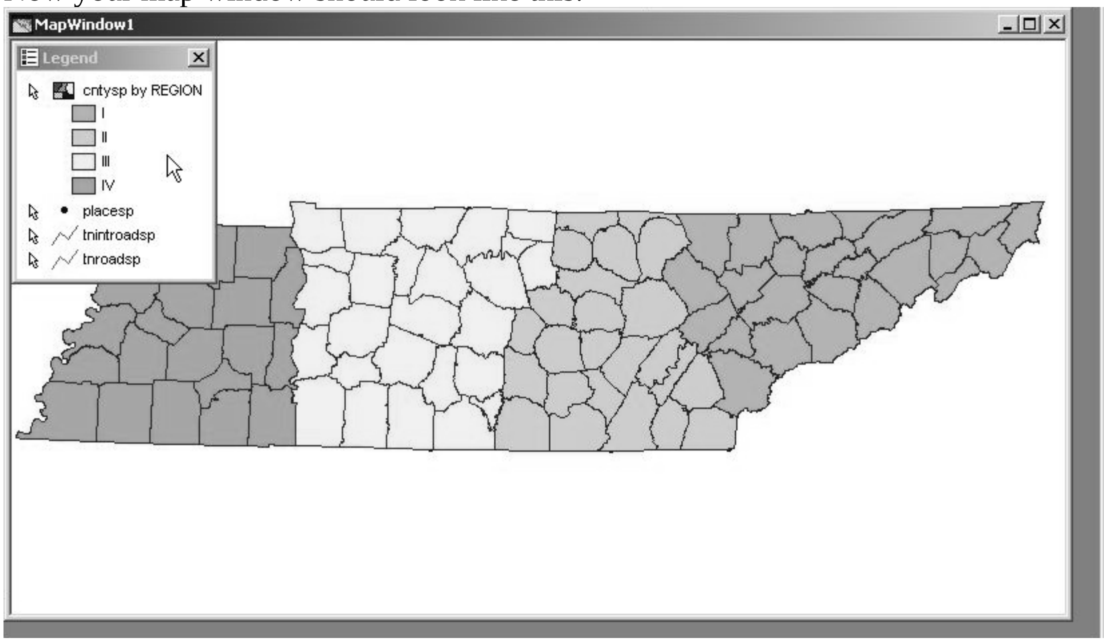
In the Add Thematic Entry dialog, click on the drop-down list and expand the ArcView connection and click on the **cntysp** feature class.



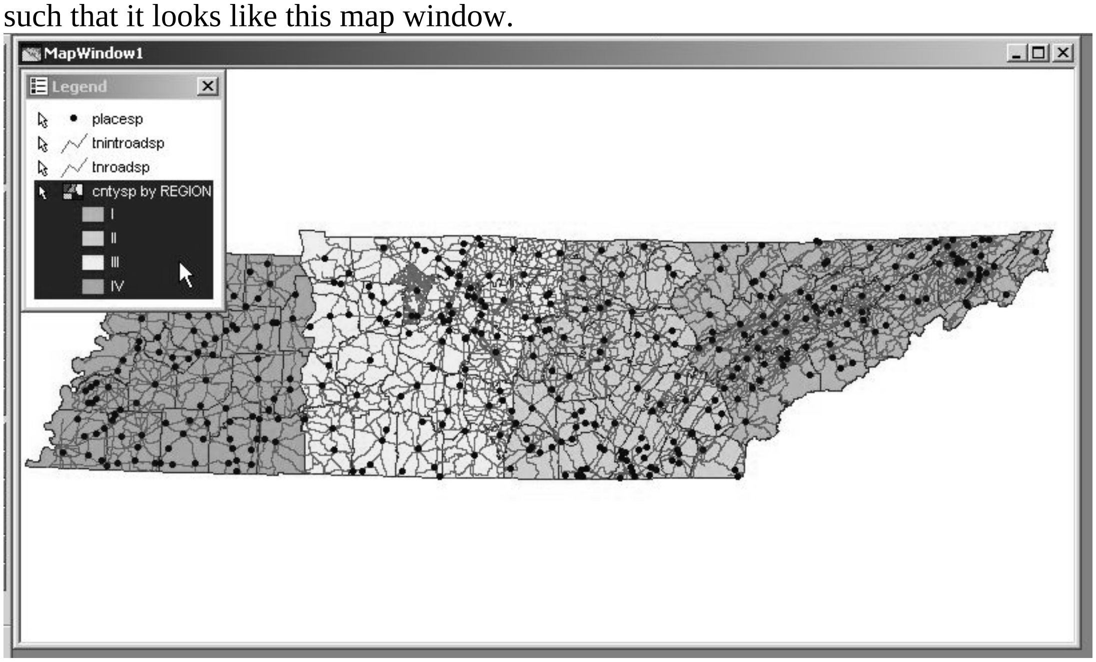
In the *Available Attributes*: list box select **REGION** and then click the **Unique** button to thematically map by TDOT region. Next click **OK**, and a thematic map of TDOT regions will appear in the map window.



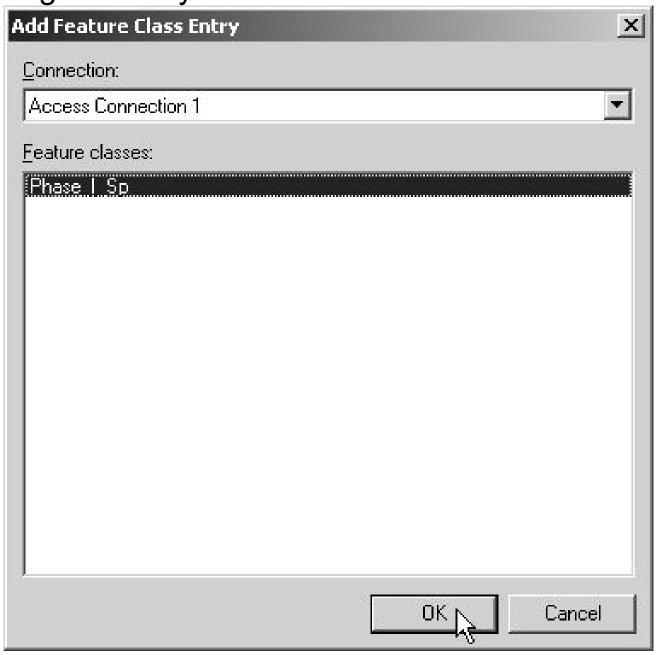
Now your map window should look like this.



Click and drag the cntysp by REGION legend entry down below the other legend entries such that it looks like this map window.



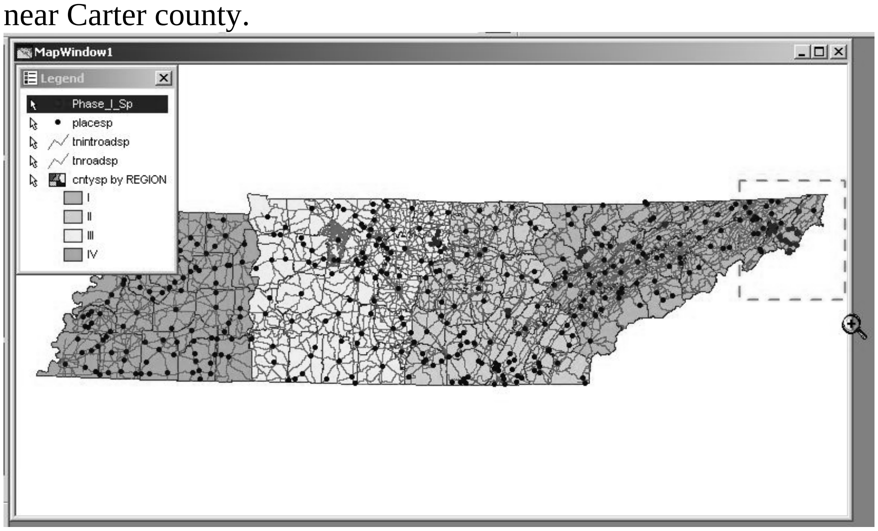
9. Now add the RHRS layer from the Access warehouse by clicking on the Add Thematic Legend Entry button as before.



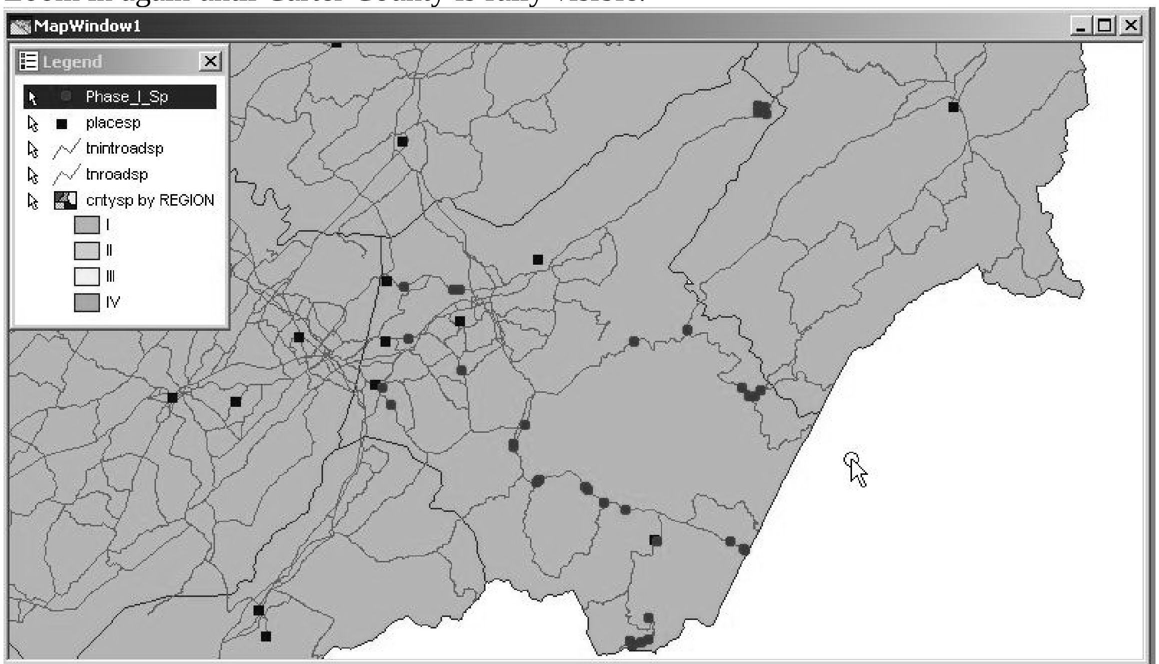
Select the Phase_I_Sp feature class and then click OK.

10. Now click on the Zoom In button on the tool bar

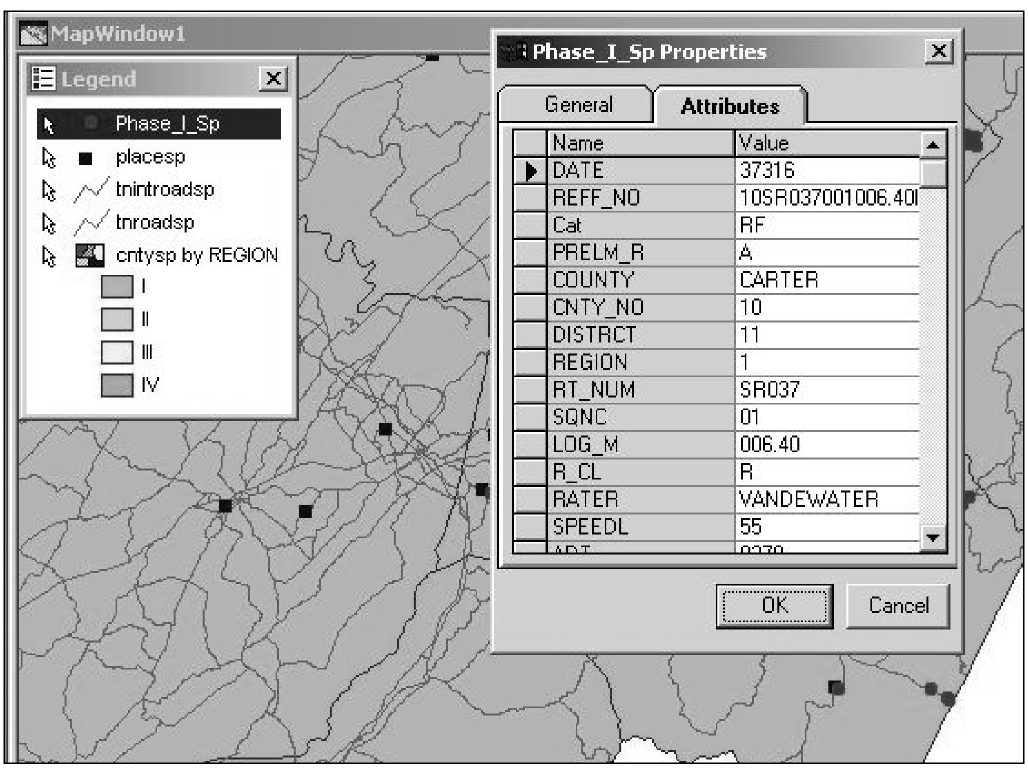
and click and drag the mouse, drawing a box around the north-eastern part of the map near Carter county.



Zoom in again until Carter County is fully visible.

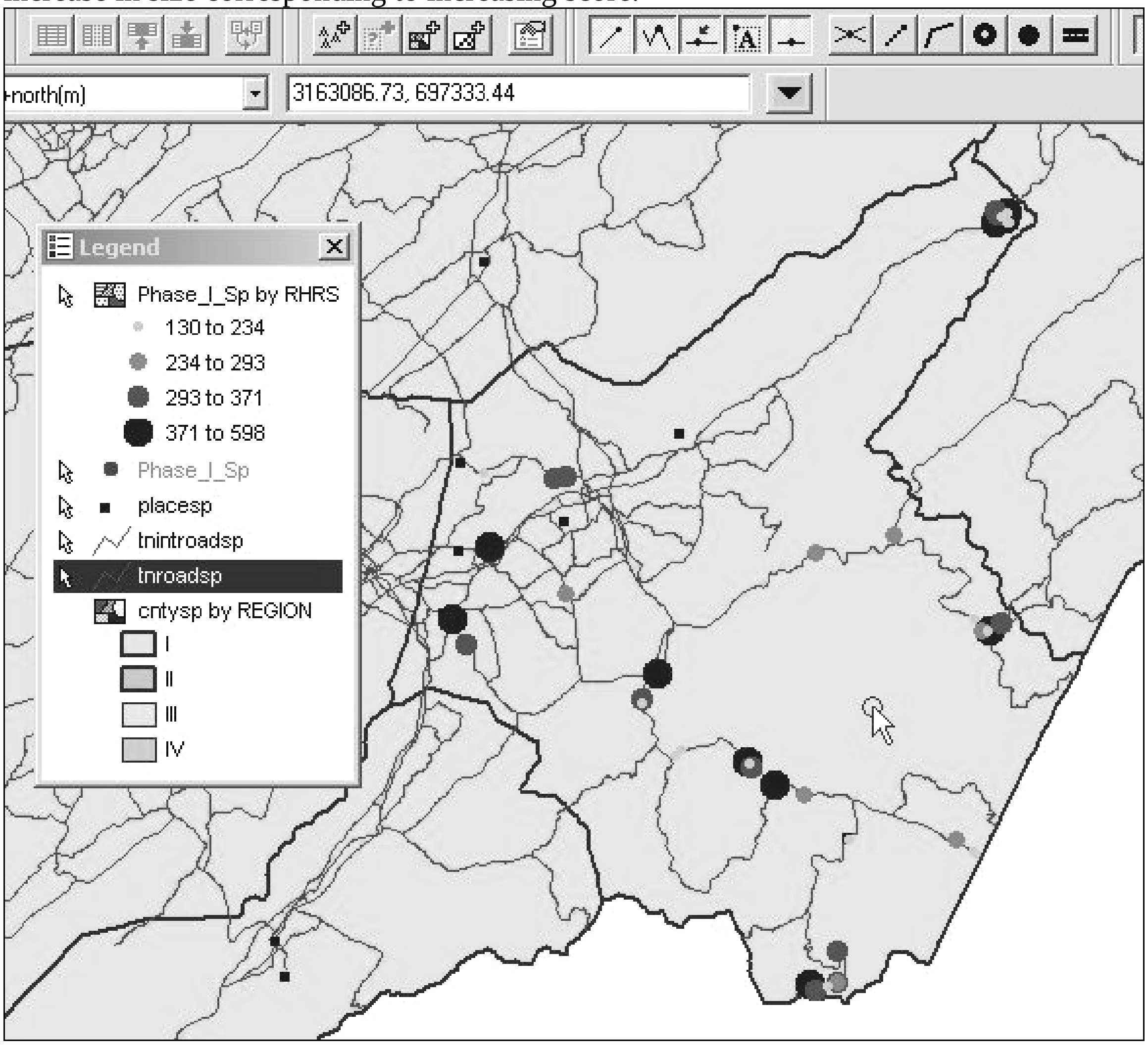


11. Zooming into any of the 5 Phase I counties will show the rock cuts that were rated as part of the RMS. Double clicking on one of the Phase_I_Sp features will bring up a feature properties dialog, which can be used to edit and view the information about a particular rock cut.



Thematic maps of the RHRS can be made in much the same way as the thematic map of the TDOT Regions. This time instead of selecting Unique, click Range for the RHRS attribute.

The resulting map can look like the following after the feature styles are edited. In this example, the feature style selected for the RHRS total score is gradient-colored circles that increase in size corresponding to increasing score.



In the above thematic map, RHRS total scores are divided into ranges, where larger and darker dots indicate higher hazard ratings. This is just one simple example of the capabilities of the RMS GIS. Thematic maps and other queries may be produced for any of the attributes recorded in the database.

Additional information on using GeoMedia may be found in the help files for GeoMedia. More general tutorials regarding using GeoMedia may be found under the help menu and clicking Learning GeoMedia Professional.

Rockfall Management System for Tennessee

Appendix G:

Work Load Summary for Field Data Collection

December 2007

TDOT

TDOT - RHRS Field Activity Time Log

Activity time includes travel time to destination from Knoxville, Tennessee

County	Region	PHASE-I				PHASE-II				TOTAL			
		Persons/team			2	Persons/team			2	Persons/team			2
		Team-Hours		Person-Hours		Team-Hours		Person-Hours		Team-Hours		Person-Hours	
		TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field
Anderson		4	32	8	64					4	32	8	64
Bedford	3					2	4	4	8	2	4	4	8
Benton	4					2	4	4	8	2	4	4	8
Bledsoe	2	4	20	8	40	2	48	4	96	6	68	12	136
Blount	1					2	144	4	288	2	144	4	288
Bradley	2					2	4	4	8	2	4	4	8
Campbell	1					2	88	4	176	2	88	4	176
Cannon	2					2	4	4	8	2	4	4	8
Carter		8	64	16	128					8	64	16	128
Cheatham	3					2	12	4	24	2	12	4	24
Claiborne	1					2	64	4	128	2	64	4	128
Clay	2					2	8	4	16	2	8	4	16
Cocke	1					2	60	4	120	2	60	4	120
Coffee	3					2	8	4	16	2	8	4	16
Cumberland	2					2	16	4	32	2	16	4	32
Davidson	3					2	180	4	360	2	180	4	360
Decatur	4					2	4	4	8	2	4	4	8
DeKalb	2					2	36	4	72	2	36	4	72
Dickson	3					2	4	4	8	2	4	4	8
Fentress	2					2	36	4	72	2	36	4	72
Franklin	2					2	12	4	24	2	12	4	24
Giles	3					2	4	4	8	2	4	4	8
Grainger		4	13	8	26					4	13	8	26
Greene	1					2	64	4	128	2	64	4	128
Grundy	2					2	36	4	72	2	36	4	72
Hamblen	1					2	4	4	8	2	4	4	8
Hamilton	2					2	48	4	96	2	48	4	96
Hancock	1					2	64	4	128	2	64	4	128
Hardin	4					2	4	4	8	2	4	4	8
Hawkins	1					2	72	4	144	2	72	4	144
Henry	4					2	4	4	8	2	4	4	8
Hickman	3					2	12	4	24	2	12	4	24
Houston	3					2	4	4	8	2	4	4	8
Humphreys	3					2	4	4	8	2	4	4	8
Jackson	2					2	48	4	96	2	48	4	96
Jefferson	1					2	4	4	8	2	4	4	8
Johnson	1					2	64	4	128	2	64	4	128
Knox	1					2	48	4	96	2	48	4	96
Lawrence	3					2	4	4	8	2	4	4	8
Lewis	3					2	4	4	8	2	4	4	8
Lincoln	3					2	8	4	16	2	8	4	16
Loudon	1					2	4	4	8	2	4	4	8
Macon	3					2	8	4	16	2	8	4	16
Marion	2					2	84	4	168	2	84	4	168
Marshall	3					2	8	4	16	2	8	4	16
Maury	3					2	8	4	16	2	8	4	16
McMinn	2					2	8	4	16	2	8	4	16
Meigs	2					2	4	4	8	2	4	4	8
Monroe	1					2	60	4	120	2	60	4	120

Montgomery	3					2	4	4	8	2	4	4	8
Moore	3					2	4	4	8	2	4	4	8
Morgan	1					2	60	4	120	2	60	4	120
Overton	2					2	48	4	96	2	48	4	96
Perry	3					2	8	4	16	2	8	4	16
Pickett	2					2	8	4	16	2	8	4	16
Polk	2					2	128	4	256	2	128	4	256
Putnam	2					2	48	4	96	2	48	4	96
Rhea	2					2	16	4	32	2	16	4	32
Roane	1					2	24	4	48	2	24	4	48
Robertson	3					2	4	4	8	2	4	4	8
Rutherford	3					2	4	4	8	2	4	4	8
Scott	1					2	20	4	40	2	20	4	40
Sequatchie	2					2	16	4	32	2	16	4	32
Sevier	1					2	156	4	312	2	156	4	312
Smith		6	44	12	88					6	44	12	88
Stewart	3					2	8	4	16	2	8	4	16
Sullivan	1					2	80	4	160	2	80	4	160
Sumner	3					2	16	4	32	2	16	4	32
Trousdale	3					2	4	4	8	2	4	4	8
Unicoi	1					2	64	4	128	2	64	4	128
Union	1					2	64	4	128	2	64	4	128
Van Buren	2					2	48	4	96	2	48	4	96
Warren	2					2	4	4	8	2	4	4	8
Washington	1					2	24	4	48	2	24	4	48
Wayne	3					2	8	4	16	2	8	4	16
White	2					2	4	4	8	2	4	4	8
Williamson	3					2	8	4	16	2	8	4	16
Wilson	3					2	8	4	16	2	8	4	16
Total (hrs)		26	173	52	346	148	2308	296	4616	174	2481	348	4962
Total (days)		3	22	7	43	19	289	37	577	22	310	44	620
Total (weeks)		1	4	1	9	4	58	7	115	4	62	9	124

TDOT - RHRS Field Activity Time Log

Activity time includes travel time to destination from Knoxville, Tennessee

		PHASE-I				PHASE-II				TOTAL			
		Persons/team			2	Persons/team			2	Persons/team			2
		Team-Hours		Person-Hours		Team-Hours		Person-Hours		Team-Hours		Person-Hours	
County	Region	TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field	TRIMS	Field
Anderson		4	32	8	64					4	32	8	64
Bedford	3					2	4	4	8	2	4	4	8
Benton	4					2	4	4	8	2	4	4	8
Bledsoe	2	4	20	8	40	2	48	4	96	6	68	12	136
Blount	1					2	144	4	288	2	144	4	288
Bradley	2					2	4	4	8	2	4	4	8
Campbell	1					2	88	4	176	2	88	4	176
Cannon	2					2	4	4	8	2	4	4	8
Carter		8	64	16	128					8	64	16	128
Cheatham	3					2	12	4	24	2	12	4	24
Claiborne	1					2	64	4	128	2	64	4	128
Clay	2					2	8	4	16	2	8	4	16
Cocke	1					2	60	4	120	2	60	4	120
Coffee	3					2	8	4	16	2	8	4	16
Cumberland	2					2	16	4	32	2	16	4	32
Davidson	3					2	180	4	360	2	180	4	360
Decatur	4					2	4	4	8	2	4	4	8
DeKalb	2					2	36	4	72	2	36	4	72
Dickson	3					2	4	4	8	2	4	4	8
Fentress	2					2	36	4	72	2	36	4	72
Franklin	2					2	12	4	24	2	12	4	24
Giles	3					2	4	4	8	2	4	4	8
Grainger		4	13	8	26					4	13	8	26
Greene	1					2	64	4	128	2	64	4	128
Grundy	2					2	36	4	72	2	36	4	72
Hamblen	1					2	4	4	8	2	4	4	8
Hamilton	2					2	48	4	96	2	48	4	96
Hancock	1					2	64	4	128	2	64	4	128
Hardin	4					2	4	4	8	2	4	4	8
Hawkins	1					2	72	4	144	2	72	4	144
Henry	4					2	4	4	8	2	4	4	8
Hickman	3					2	12	4	24	2	12	4	24
Houston	3					2	4	4	8	2	4	4	8
Humphreys	3					2	4	4	8	2	4	4	8
Jackson	2					2	48	4	96	2	48	4	96
Jefferson	1					2	4	4	8	2	4	4	8
Johnson	1					2	64	4	128	2	64	4	128
Knox	1					2	48	4	96	2	48	4	96
Lawrence	3					2	4	4	8	2	4	4	8
Lewis	3					2	4	4	8	2	4	4	8
Lincoln	3					2	8	4	16	2	8	4	16
Loudon	1					2	4	4	8	2	4	4	8
Macon	3					2	8	4	16	2	8	4	16
Marion	2					2	84	4	168	2	84	4	168
Marshall	3					2	8	4	16	2	8	4	16
Maury	3					2	8	4	16	2	8	4	16
McMinn	2					2	8	4	16	2	8	4	16
Meigs	2					2	4	4	8	2	4	4	8
Monroe	1					2	60	4	120	2	60	4	120

Montgomery	*3*					2	4	4	8	2	4	4	8
Moore	*3*					2	4	4	8	2	4	4	8
Morgan	*1*					2	60	4	120	2	60	4	120
Overton	*2*					2	48	4	96	2	48	4	96
Perry	*3*					2	8	4	16	2	8	4	16
Pickett	*2*					2	8	4	16	2	8	4	16
Polk	*2*					2	128	4	256	2	128	4	256
Putnam	*2*					2	48	4	96	2	48	4	96
Rhea	*2*					2	16	4	32	2	16	4	32
Roane	*1*					2	24	4	48	2	24	4	48
Robertson	*3*					2	4	4	8	2	4	4	8
Rutherford	*3*					2	4	4	8	2	4	4	8
Scott	*1*					2	20	4	40	2	20	4	40
Sequatchie	*2*					2	16	4	32	2	16	4	32
Sevier	*1*					2	156	4	312	2	156	4	312
Smith		6	44	12	88					6	44	12	88
Stewart	*3*					2	8	4	16	2	8	4	16
Sullivan	*1*					2	80	4	160	2	80	4	160
Sumner	*3*					2	16	4	32	2	16	4	32
Trousdale	*3*					2	4	4	8	2	4	4	8
Unicoi	*1*					2	64	4	128	2	64	4	128
Union	*1*					2	64	4	128	2	64	4	128
Van Buren	*2*					2	48	4	96	2	48	4	96
Warren	*2*					2	4	4	8	2	4	4	8
Washington	*1*					2	24	4	48	2	24	4	48
Wayne	*3*					2	8	4	16	2	8	4	16
White	*2*					2	4	4	8	2	4	4	8
Williamson	*3*					2	8	4	16	2	8	4	16
Wilson	*3*					2	8	4	16	2	8	4	16
Total (hrs)		26	173	52	346	148	2308	296	4616	174	2481	348	4962
Total (days)		3	22	7	43	19	289	37	577	22	310	44	620
Total (weeks)		1	4	1	9	4	58	7	115	4	62	9	124

Rockfall Management System for Tennessee

Appendix H:

Electronic Data Collection

December 2007

TDOT

Electronic Data Collection for Rockfall Analysis

1. Abstract

Rockfall analysis traditionally has used conventional stationary tools, i.e. pencil and paper, for data collection. Traditional methodologies are being revisited with the advent of PDA's (Personal Digital Assistants) or pen-based computers. With the utilization of such technology, field data can be collected electronically. The advantages over pencil and paper data collection include the elimination of manual data entry following the fieldwork, and automatic error and data integrity checks during data input. The PDA's also allow automatic branching to solicit data input based on previous data entered, and support for code or scripting which can be used to create unique files names based on the data entered. These advantages are illustrated in an electronic data collection methodology as implemented within a rockfall hazard rating system for the TDOT (Tennessee Department of Transportation).

2. Introduction

Rockfall hazard rating systems are used by a number of agencies to rate highway rock slopes in terms of the potential hazard to the motoring public. While several rating systems are in use, they usually require the collection of various field data, ranging from traffic information to geologic structure and climate. This data collection has traditionally been done with paper forms, usually with the field data manually entered into a computer database or spreadsheet at a later time. Personal Digital Assistants (PDA's) or pen-based computers offer opportunities to enter field data directly and efficiently in a digital format that can be downloaded directly to a database.

PDA's have been employed in various applications of Civil Engineering. Several studies have been conducted to examine the use of PDA's as data collection devices (1-5). More and more uses of such technology are being employed. This paper describes the use of PDA's for electronic data collection for rockfall hazard rating.

3. ROCKFALL HAZARD RATING SYSTEM

Rockfall hazard rating systems have been used to assign a hazard rating to rock slopes and to assist in the prioritization of repair with maintenance activities. The rockfall hazard rating system developed by the Oregon Department of Transportation (ODOT), then adopted by National Highway Institute (NHI) (6), has been widely used. Several states and provinces including Colorado, Oregon, New York State, North Carolina, and Ontario have utilized this system or a variant of this system (7). The state of Tennessee, in an effort to take an active approach to rockfall hazards, has modified the existing rockfall hazard rating system developed by the NHI. The modifications were established as a result of a 2-year pilot study gathering information from 5 counties in Tennessee, which were selected to be representative of the diverse geologic conditions present in Tennessee. The modifications to the NHI were thought to provide more detailed and informative input regarding the pertinent geologic characteristics, and to improve repeatability and consistency among raters (8).

The proposed Tennessee rockfall hazard rating system, like the NHI system, is composed of two phases: a preliminary rating and a detailed rating. The primary purpose of the preliminary rating is to identify slopes requiring additional investigation. Slopes are rated A, B, or C. "A" rated slopes are subjected further to detailed ratings, "B" rated slopes are recorded for monitoring purposes, and C slopes are not recorded because they represent either low estimated potential for rockfall on the road way or have had low historical rockfall activity. The primary purpose of the detailed rating is to capture data necessary to differentiate and assess the hazard of a particular site. The detailed rating then can be used to prioritize hazardous sites based on the scores received from the ratings. Detailed rating criteria and the Tennessee modifications to the NHI system are described by Vanderwater (8). This paper describes the development of electronic data collection forms for both the preliminary and detailed ratings of rock slopes in Tennessee.

4. Electronic Data Collection

A. Platform Selection

Platform selection details identifying cost and functional features of the software package. Examples of functional features are creation of customized forms, downloading and merging with existing data, and scripting. A number of software packages were evaluated with functional features as the evaluation criteria. Pendragon Forms 3.1, later upgraded to 3.2, which runs on the Palm OS, was selected.

B. Pendragon Forms

Pendragon Forms allows for the creation of customized forms (9). To customize forms, the software has several types of fields, as shown in Figure 1. Figure 1a is an example numeric field for Average Daily Traffic (ADT), which only allows numeric data to be entered into the field and displays a numeric keypad to assist the user in entering data. Figure 1b is an example pop-up menu, where the user selects from a data set, which in this case is the Preliminary Rating. Note, only choices of A or B are provided since data is not collected for C slopes. Figure 1c is a numeric field with a default value entered when the user views the screen. Several of the field types use default values, which aid in the ability to complete the form in a timely manner. Figure 1d is an option field used to determine the Department of Transportation region of the state. Based on the region selected, the corresponding counties are then displayed. Figure 1e is a lookup field that is based on a previous option field. Figure 1f is a lookup field response, which is displayed after the button is selected.

Advanced properties within Pendragon allow for the automation of certain types of fields. Each type of field has different attributes, which improves data integrity. Using a combination of fields, Pendragon Forms was used to create the Rockfall Hazard Rating System electronic data collection form. Pendragon is an application primarily developed for use with Microsoft Access 97 and Microsoft Access 2000. However, the data can be exported to any database or table capable of reading an ASCII file, therefore the data is not restricted by Access. Within Pendragon Forms, forms are created on the desktop computer and sent to the handheld device during a HotSync data transfer. Once a form is installed on the handheld, records can be created to store data. Pendragon allows for bi-directional synchronization of information that is, records on the PC are automatically sent to the handheld, and records entered on the handheld are automatically sent to the PC. If there is a conflict in which the same record is modified on the handheld and the PC, a synchronization rule can be setup either to have the handheld overwrite the PC or the PC overwrite the handheld (9).

C. Advantages of Electronic Data Collection

Electronic data collection provides several advantages over conventional data collection methods. Elimination of clipboards, paper maps, hand written worksheets, and the collection of more data in less time are a few basic advantages over the conventional paper-based data collection methods. Other advantages include the elimination of data re-entry, branching, real-time error checking, integrated GPS (Global Positioning System) interface, and enhanced data integrity.

1. Elimination of data re-entry

Collecting data using stationary items such as pen and paper leaves the task of transferring data into electronic format. Post-processing of data into electronic media often involves manual data entry, which is susceptible to error. This process is often time intensive and costly. Using the proposed electronic data collection system eliminates the use of data re-entry since the data is initially entered electronically. In addition, it saves time, money, eliminates error due to re-entry.

2. Branching (Scripting)

3. **Branching is a process by which the form designer writes codes or scripts to have the form display what a user sees based on the previous user response (9). Figure 2 demonstrates the use of branching. In this example if the previous height is okay then it proceeds to the next field, which is a numeric input. On the other hand, if the previous height is not okay, then it returns to the height determination screen to revisit the height information. Real-time Error Checking (Scripting)**

Implementation of real-time error checking is facilitated through the use of Pendragon Forms' *advanced field properties* such as scripting. Scripting allows the developer to control the events before and after a user views a particular field. In addition, scripting permits calculations within and on fields, allows for branching, and minimizes data entry by pre-filling fields (9). Figure 3 illustrates three common error types namely, *f*orm *message*, *missing response*, and *value not allowed*. *Form message* is the result of creating a custom message as shown in Figure 3a. Figure 3a illustrates the error displayed when the user enters a value that violates the relationship between known field parameters. In this example, the alpha value, previously entered, must be less than the beta value, but it is not thus the error message is displayed. Figure 3b is an example of a *missing response* error. If a required field is not completed, an error message as seen in Figure 3b will be displayed allowing the user to edit the data. Another type of error is the *value not entered* error message as seen in Figure 3c. The value not allowed error message in this case results from a violation of the pre-established range. Similarly, a *value not allowed* error message can be generated by entering an alphanumeric response in a numeric only field, as shown in Figure 3d. The resulting *value not allowed* error is displayed as shown in Figure 3e.

4. Integrated GPS Interface

Spatial data such as GPS coordinates can be recorded in the proposed electronic data collection system through scripting. Pendragon Forms permits an attached device to transmit data via the serial port of the PDA (9). From an attached GPS unit, as shown in Figure 4, or an external GPS unit (attached to the serial port), coordinates (spatial data) can be gathered for the rock slope. This allows the data to become part of a GIS (Geographic Information System) (10). Figure 5a illustrates a button field used to acquire the GPS coordinates. Coordinates for the longitude, latitude, and elevation are received by the PDA as one string as shown in Figure 5b. Figure 5c indicates that the correct string was received by the PDA. In the case the string is incorrect or incomplete, Figure 5d is displayed and the unit returns to the GPS acquired screen, Figure 5a. Once the correct string is recorded, longitude, latitude, and elevation are displayed as shown in Figure 5e-5f, respectively. Alternatively, the GPS data may be entered directly using a numeric field.

5. Data Integrity (Field Selection)

The system allows a developer with prior knowledge of data characteristics (numeric, alpha-numeric, categorical, etc.) to select field types corresponding to the specified data type. Selecting field types corresponding to the data type will only allow that specific data type to be entered. For example, ADT stores the number of vehicles per day. As it is known that the ADT represents a numeric quantity, a numeric field can be used. Figure 1a demonstrates the use of a numeric field. Using the numeric field type improves data integrity because only numeric data can be entered into the field. In addition, a keypad is displayed for the user, which aids in character recognition. If the user enters alphanumeric data in a numeric-only field, an error will be displayed. Other field types such as the popup menu illustrated in Figure 1b maybe utilized to aid in data integrity as well. Knowing the preliminary rating choices are either A or B, a pop-up menu with these values maybe utilized to save time and avoid complication with character recognition. Utilizing various field type combinations promote data integrity by limiting data that is not representative of the field type. Figure 1 shows several example field types.

Data integrity is also improved by scripting. Scripting can be used to develop unique identifiers such as the file number in the proposed data collection system. The file number, consistent with TRIMS (Tennessee Road Information Management System), is composed of six parameters from the rated site which are meshed into one string in the following order, county number, road number, special case, county sequence, beginning log mile, and reference to the centerline. Figure 6 illustrates the concatenation of the parameters. The accuracy of the file number is vital to the record being stored correctly and comparison with other TDOT data. The PDA has the ability to assemble this string automatically from the data input.

5. Conclusions

An electronic data collection system was developed for rockfall analysis incorporating features such as real-time error checking, branching, popup menus, numeric keypads, and enhanced data integrity. Commercially available software permits the development of these custom forms, and examples were described for various data types related to rockfall hazard rating systems. The system's main advantage over conventional methods is the elimination of data re-entry and the ability to retrieve data to generate critical, but unique, informational strings such as the file number. Furthermore, electronic data collection is an efficient and effective means of collecting data. The capabilities of these systems are only limited by the ability of the mind to find new applications for the technology.

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5. McCullouch, Bob. Automating Field Data Collection in Construction Organizations. Proceedings of the Construction Congress V. October1997, pp. 957-963.
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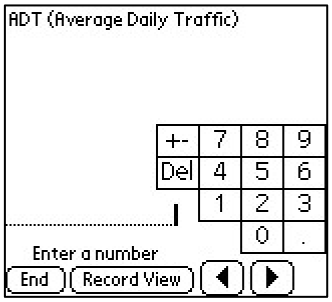
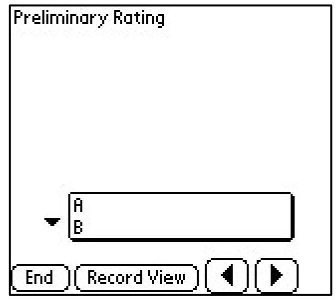
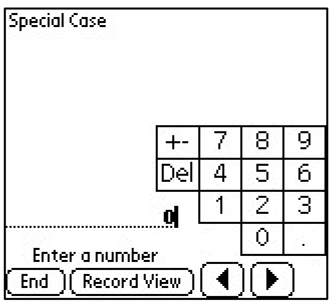


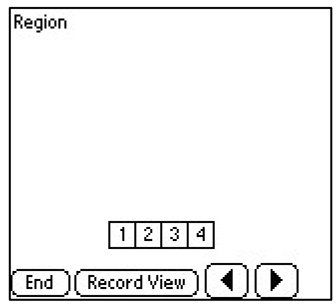
a. Numeric field



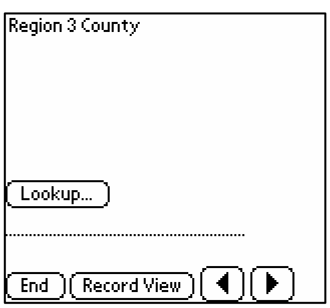
b. Pop-up menu



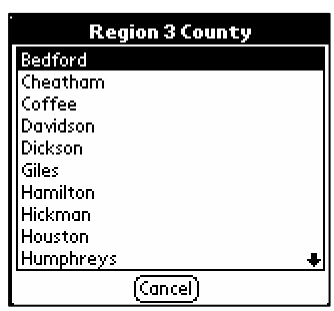
c. Numeric field with default value



d. Option field



e. Lookup field



f. Lookup field response

FIGURE 1 Example field types (a) numeric fields (b) pop-up menu (c) numeric field with default value (d) option field with choices 1-4 (e) lookup field (f) look up field response

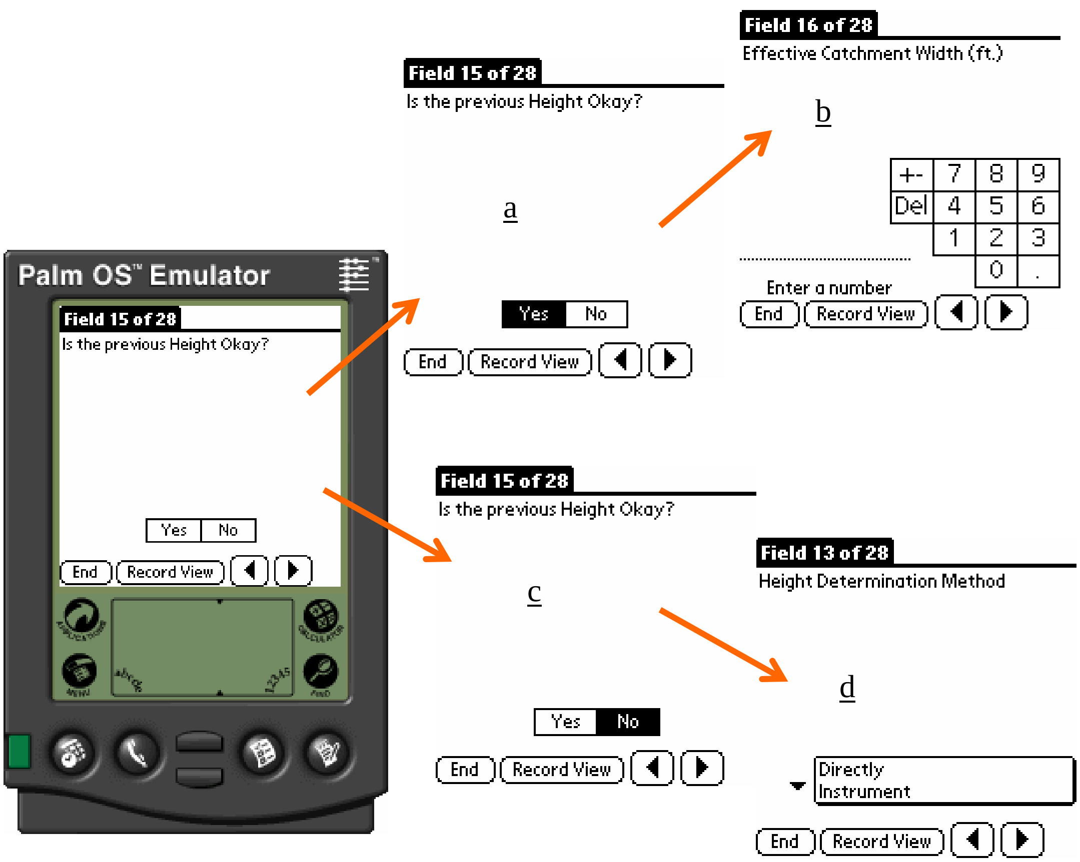
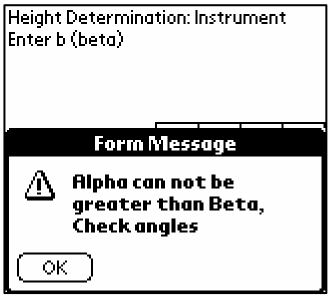
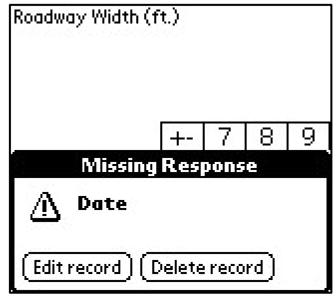


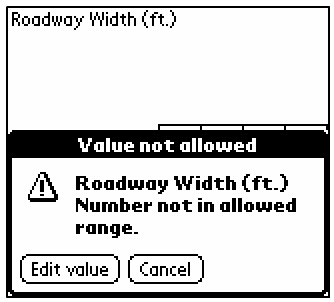
FIGURE 2 Branching (a) If the response to the question is “Yes” (b) Numeric field after “Yes” response (c) If the response to question is “No” (d) Pop-up menu to select the method to reevaluate the high



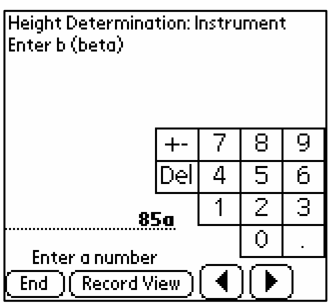
a. Scripting error



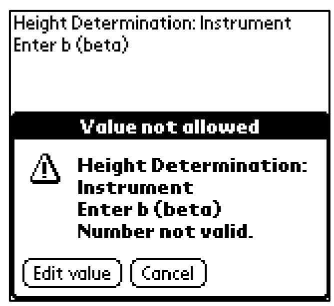
b. Missing data error message



c. Range error message



d. Numeric only field with alphanumeric



e. Numeric only field with alphanumeric data error

FIGURE 3 Sample error messages

(a) Scripting error message in response to incorrect alpha angle being greater than beta angle for height determination
(b) Missing data error message that occurs when form is ended without all the required fields containing data
(c) Range error message in response to a entered value not within specified maximum and minimum values
(d) Numeric only field with alphanumeric data
(e) Numeric only field with alphanumeric data error message

FIGURE 4. Palm PDA with attached GPS receiver

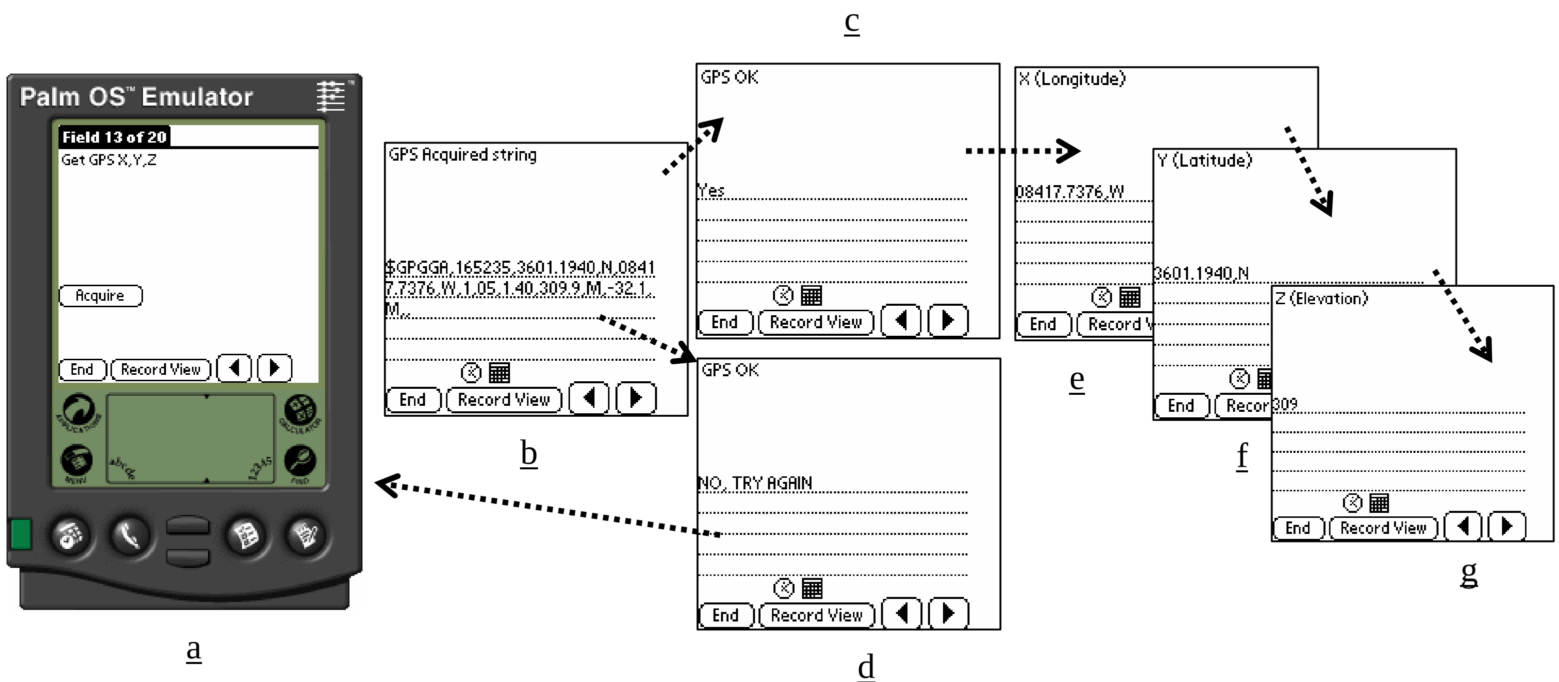


FIGURE 5 Integrated collection of GPS coordinates (a) field displaying GPS Acquire button (b) field displaying GPS acquired string (c) field inquiring if the acquired GPS string is the correct string with positive response (d) field displaying response of incorrect GPS string which returns to the acquire screen (e) automated longitude from GPS string (f) automated

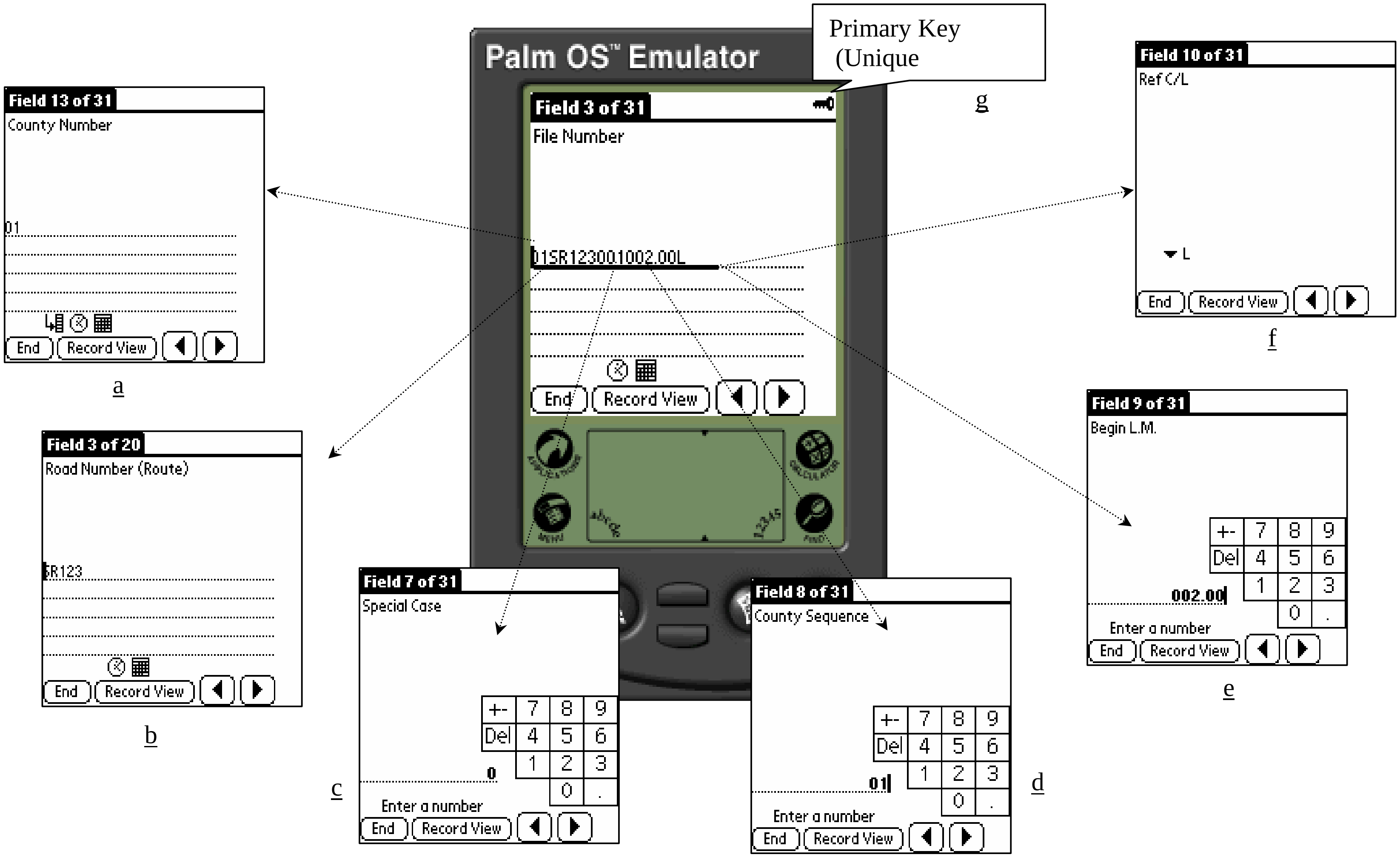


FIGURE 6. File number concatenation (a) county number field (b) route number field (c) special case field (d) county sequence field (e) beginning log mile field (f) reference to center line field (g) prime key identifier that is used to merge with other existing data. Note: The order in which the fields are collected is not imperative. For example, county number is the first parameter in the file number however it is the last field for which data is collected.

Rockfall Management System for Tennessee

Appendix I:

Database Integration

December 2007

TDOT

Database integration

During field data collection, data pertaining to rockfall risk are collected on a PDA (Figure 1) by one or more field crews. The data are synchronized daily with laptop computers maintained by each of the crews. When a crew returns to its office, rockfall risk information is exported and transferred to a central Access database maintained by the database administrator (DBA). The above procedure allows the data to be checked at

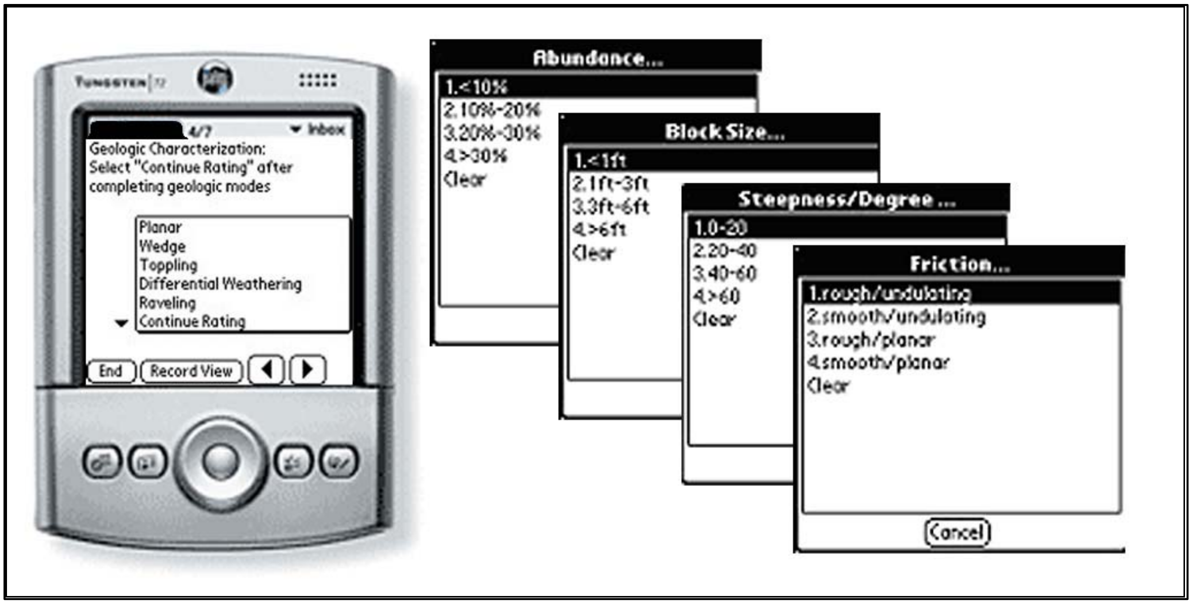


Figure 1. Palm computer with example input forms. Selection of plane or wedge (displayed on the PDA) results in successive activation of the forms (on right) used to assess that mode of failure.

different stages by both field crew leaders and the DBA. The field team leader verifies the accuracy of the data as it is collected in the field, and again each evening after it is downloaded from a PDA. The DBA merges all records into the appropriate tables and ensures the integrity of the data as it is transferred to the central Access database.

The central Access database maintains a direct active link to the Oracle rockfall database via Oracle Migration Workbench (Oracle, 2005). The rockfall risk data in the Access database is mirrored in tables within an Oracle database scheme. As data are added to the Access database, the Oracle database is automatically updated. Each update event triggers a custom script within Oracle that builds the spatial reference from the log mile location, using dynamic segmentation (Kiel et al. 1999; Sutton and Wyman 2000). The geographic reference is stored using the Oracle spatial object model as a linear feature along the road. Where conditions allowed, GPS coordinates were also obtained for all sites and stored in the database for comparison to locations derived from dynamic segmentation.

The rockfall risk database schema is made up of several tables and sub-tables that store a variety of information related to rockcuts and rockfall risk (Figure 2). The tables and sub-tables are grouped into functional groups (Table 1). The central rockfall database also contains indexes and views (Greenwald et al., 2004) that provide more efficient access to rockfall information. The views are PL/SQL statements that are stored in the database. When executed, they present data from the base tables in the manner specified by the query (Connolly and Begg, 2005). The views are used to present the data in a readable format or to extract aggregated data for analysis.

The GIS provides a convenient interface for browsing RMS data. Users can view maps at any scale or by region, district or county. The interface provides simple tools for honing in on areas of interest by means of spatial or attribute selection, and allows the user to browse and edit the data to verify correctness. The rockfall information can also be mapped based on any of the measures recorded in the field, or based on other layers such as geology. Thematic maps of rockfall potential can be used to see which counties or state routes have the highest incidence of rock slopes with high risk potential (Figure 3).

The GIS can be used to calculate the number of slopes rated above a certain level, per mile of road within each county. Spatial analysis of the different layers viewed in the GIS can be used to study correlations among hazardous slopes, geology, topography and other factors. As data are added to TennRMS, additional data summaries and statistical operations can be performed to deduce a variety of correlations between rockfall occurrence, risks, failure modes, remediation costs & strategies and seasonal variations.

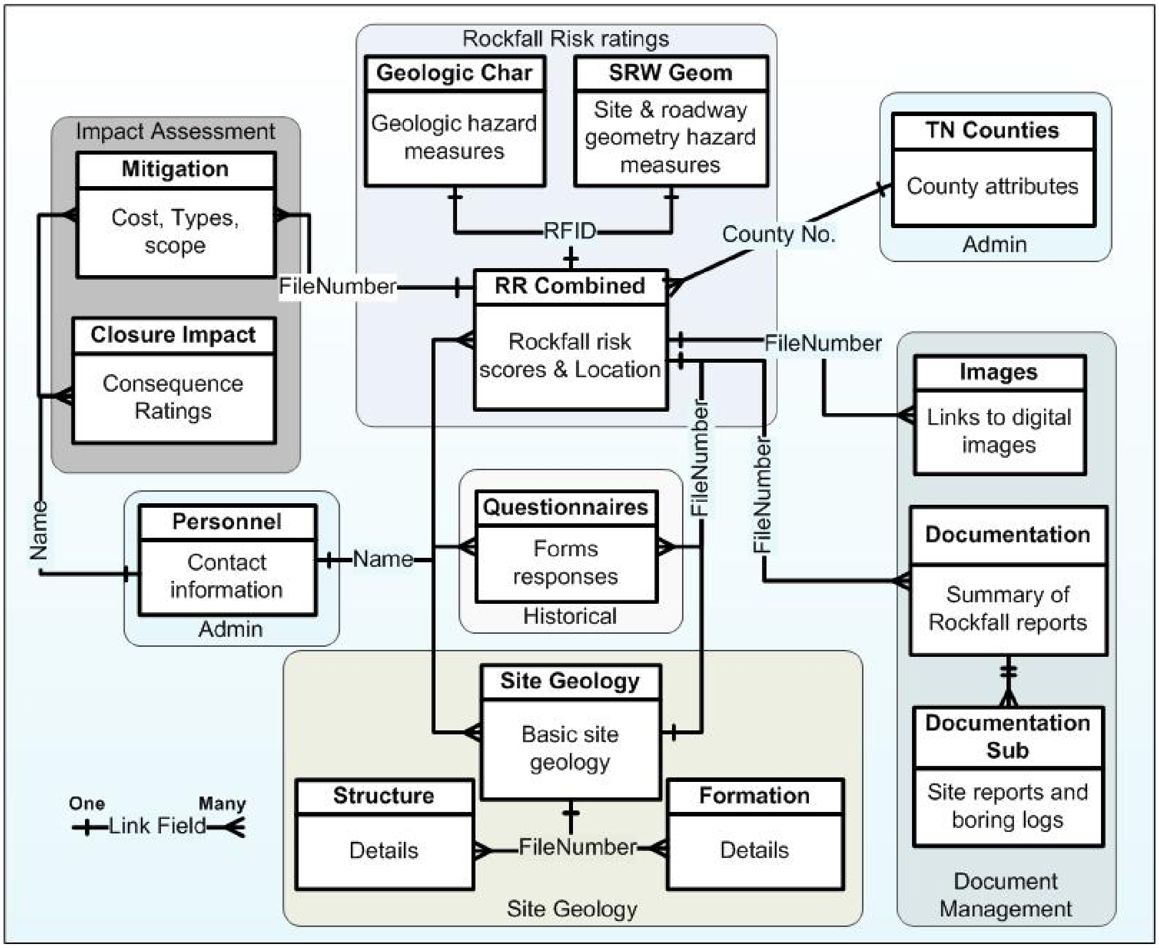


Figure 2. Generalized entity relationship diagram for the Rockfall Risk database (after Bateman, 2003). The main blocks correspond to the functional groups in Table 3. Relational links are between individual tables are depicted.

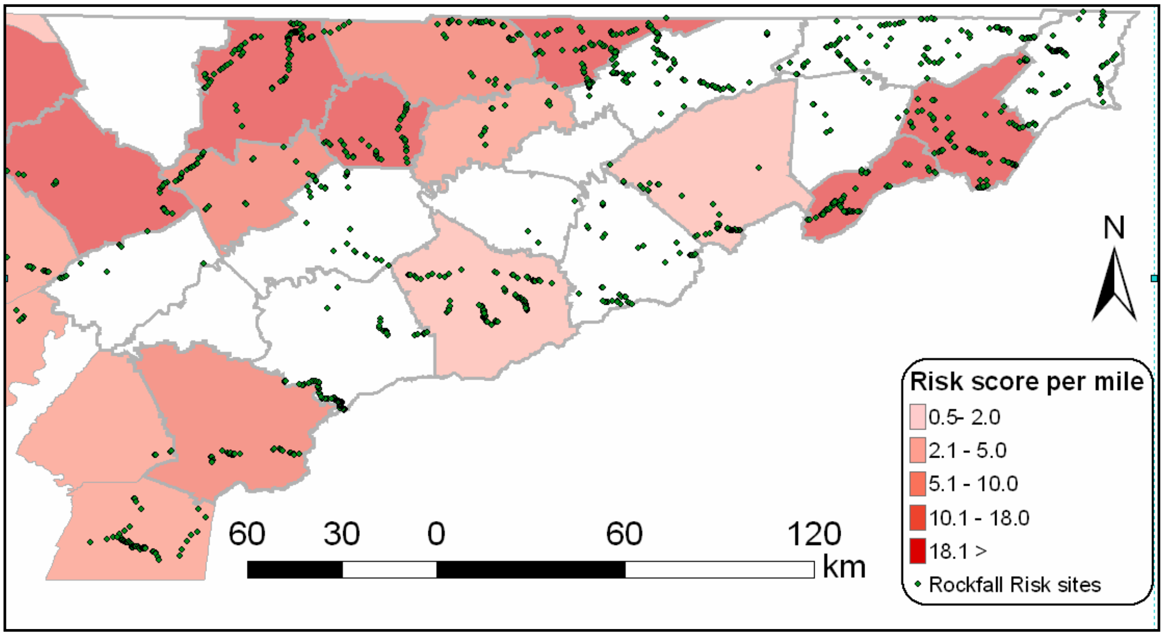


Figure 3.Thematic map of east Tennessee contains TDOT Region 1 counties showing the rockfall risk rating per mile of road and black dots are rockfall risk sites.

Table 1. Rockfall risk database tables and functional groups.

Group	Table Name	Description
Rockfall Risk Rating	*Rockfall Risk*	Base-table that stores location attribute information includes road number, mile marker, and GPS coordinates. Contains all the information used to develop the rockfall risk scores
	Site & Roadway Geometry	Sub-table that contains details related to the rockcut and roadway such as speed limit, average daily traffic, roadway width, length of rock cut, rock slope height, and decision sign distance.
	Geologic Character	Sub-table that contains the measures related to the structure-related failure modes (wedge, planar, and topple) and weathering failure modes: (raveling and differential weathering)
Geology	*Site Geology Tables*	Basic geologic information about specific rockfall sites. Sub tables for geologic formation and structural information
Historical	*Landslides*	Historical landslide inventory information
	Questionnaire	Questionnaire sent to all maintenance districts within TDOT, during the late 1980's and early 1990's, requesting locations of rockfall maintenance sites. This table contains the responses to that questionnaire.
Document Management	*Documents & Picture Locations*	Rockfall project reports are filed by TDOT based on the county in which the problem occurred. This Table contains the physical location and/or electronic link of rockfall reports, boring logs, and other documentation. Links to the digital images taken during risk rating are stored in this table, along with time stamps. In addition, locations of pictures that were taken as part of the questionnaire effort can be found in this table.
Impact Assessment	*Design Element*	Lookup table that provides cost of a design element, specifications, units and comments about the elements used in remediation and risk mitigation.
	Cost Notes	Maintains notes taken in the field regarding possible repairs and their costs.
	Elements at Risk	Lookup list describes types and costs of TDOT assets at possible risk to rockfall
	RCI	Rockfall closure impact rating information (Bateman, 2004)
	Design Mitigation	Contains information related to rockfall mitigation design & cost.
Administrative	*Personnel*	List of names and contact information of all TDOT personnel working on rockfall risk issues
	TN Counties	List of Tennessee counties and their status within TennRMS

Information Distribution & Analysis

The database is accessed via a web-based GIS interface that provides the user with the ability to map, browse and analyze TennRMS data. TDOT policy restrictions prevent direct edit access to the database via web-based applications. Therefore, TennRMS data is edited and maintained with an Access database front end that mirrors the Oracle database. The Access database is used as an operational data store for collecting, editing and maintaining rockfall information. Access to the interface is limited to TDOT's Local Area Network (LAN). Users outside the LAN can gain access using a Virtual Private Network (VPN) administered by TDOT. Users can access stored views or develop their own queries in a point-and-click interface from within the web-based GIS. The rockfall location information can be mapped with other spatial data layers from outside the RMS such as hydrography, physiography and geology. RMS data is also made available to desktop GIS applications for more sophisticated analysis via the central Oracle database.

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Kiel, D., W. Rasdorf, E. Shuller, and R. Poole (1999) Linear Referencing System for North Carolina Department of Transportation, Transportation Research Board, Transportation Research Record No. 1660, Part 2: Improving Transportation Data., pp. 108 – 113

Oracle (2005) Oracle® Migration Workbench: User's Guide. Release 10.1.0 for Microsoft Windows 98/2000/NT/XP and Linux x86. Part No. B15857-01

Sutton, J. C., and Wyman, M. M. (2000). "Dynamic location: an iconic model to synchronize temporal and spatial transportation data." Transportation Research Part C, 8, 37-52.

Rockfall Management System for Tennessee

Appendix J:

List of Publications

December 2007

List of Publications & Presentations

Papers

Bateman, V., "Rockfall Closure Impact and Economic Assessment for Rockfall Sites in Tennessee", 55th Highway Geology Symposium, Kansas City, Mo, 2004

Bateman, V., "Development of a Database to Manage Rockfall Hazard: The Tennessee Rockfall Hazard Database", Proceeding of 82nd Annual Meeting of the Transportation Research Board, Paper No. 02-3624, Washington, DC, 2002

Bellamy, D., Bateman, V., Drumm, E., Dunne, W., Vandewater, C., Mauldon, M., Rose, B., "Electronic Data Collection for Rockfall Analysis", Transportation Research Record: Geology and Properties of Earth Materials, No. 1821, Paper No. 03-3136, Transportation Research Board, Washington, DC pp 97 – 103, 2003

Rose, B., Mauldon, M., Bateman, V., Drumm, E., and Dunne, W. "Rockfall Management System and Spatial Analysis of Rock Cuts", Proceedings of Soil and Rock America 2003: 12th Pan-American Conference on Soil Mechanics and Geotechnical Engineering & 39th U.S. Rock Mechanics Symposium, June 22 - 26, 2003, Cambridge, Massachusetts, USA, pp 193 – 198, 2003

Rose, B., Mauldon, M., Bateman, V., Bellamy, D., Drumm, E., Vanderwater, C., and Dunne, W. "Data Collection, Visualization, and Distribution for Rockfall Management Systems", CE World: ASCE's First Virtual World Congress for Civil Engineering, 2001 http://www.ceworld.org

Vandewater, C.J., Dunne, W.M., Mauldon, M., Drumm, E.C., and Bateman, V. Classifying and Assessing the Contribution of Geology to Rockfall Hazard, Environmental & Engineering Geoscience MS 684 May 2005

Abstracts

Drumm, E.C., Dunne, W. M., Mauldon, M., Bateman, V. Rose B., Bellamy, D., Vandewater C. "Rockfall Management System (RMS) for Tennessee", presented at the Southeastern Transportation Geotechnical Engineering Conference, Roanoke, VA, 2001

Mauldon, M., B. Rose, S. Cain, V. Bateman E. C. Drumm, W. M. Dunne, "Assessing Rockfall Hazards Along Tennessee Highways", Association of Engineering Geologists, 46th Annual Meeting, Vail, Colorado, Sept 15 - 21, 2003

Mauldon, M., B. Rose, E. C. Drumm, and H. Moore, "Enterprise-Wide Geotechnical Information Management," presented at the Southeastern Transportation Geotechnical Engineering Conference, Roanoke, VA, 2001

Rose, B., M. Mauldon, A. La Rosa, B. Ralston, and E. C. Drumm "Using Web-Based GIS to Manage Landslide Information," presented at the Southeastern Transportation Geotechnical Engineering Conference, Roanoke, VA, 2001

Presentations

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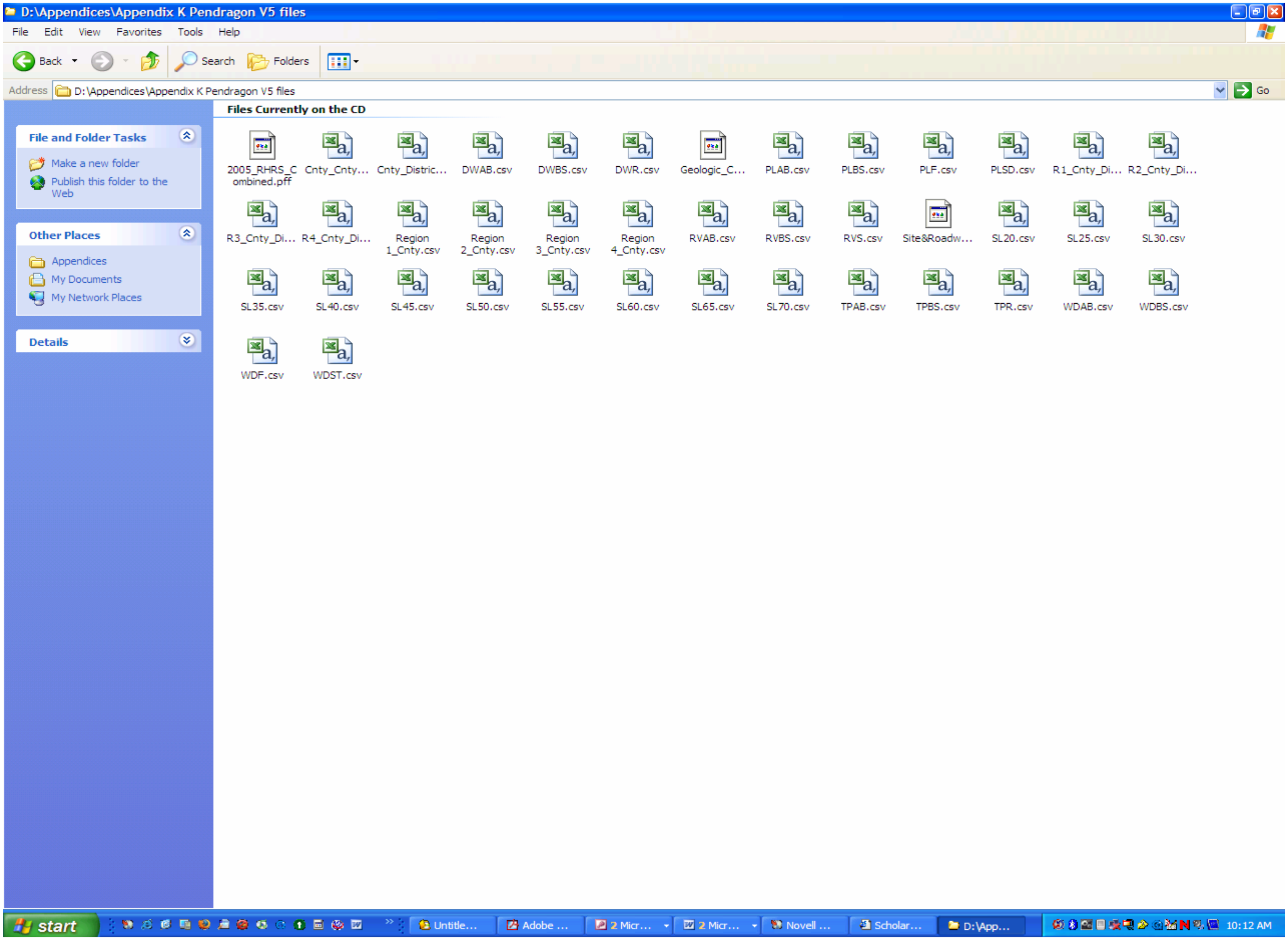
Rose, B. (2004), Tennessee Rockfall Management System Poster, CGPR Annual Member’s Meeting, Blacksburg, VA

Rockfall Management System for Tennessee

Appendix K:

Pendragon Computer files

December 2007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File Edit View Favorites Tools Help
Back
Search
Folders
Address D:\Appendices\Appendix K Pendragon V5 files
Go
Files Currently on the CD
File and Folder Tasks
Make a new folder
Publish this folder to the Web
Other Places
Appendices
My Documents
My Network Places
Details
2005_RHRS_Combined.pff
Cnty_Cnty...
Cnty_Distric...
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DWBS.csv
DWR.csv
Geologic_C...
PLAB.csv
PLBS.csv
PLF.csv
PLSD.csv
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R2_Cnty_Di...
R3_Cnty_Di...
R4_Cnty_Di...
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Region 2_Cnty.csv
Region 3_Cnty.csv
Region 4_Cnty.csv
RVAB.csv
RVBS.csv
RVS.csv
Site&Roadw...
SL20.csv
SL25.csv
SL30.csv
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SL40.csv
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Novell ...
Scholar...
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Rockfall Management System for Tennessee

Appendix L:

Field photograph Library Structure

December 2007

TDOT

Appendix L - Field Photograph Library Structure

This appendix contains the field photographs. The field photographs comprise approximately 3 GB and are included on a separate DVD. The directory structure for the field photograph library is shown below. The folders shown in the list below each contain numerous image files.

Region I

Region I\01-Anderson

Region I\01-Anderson\SR009

Region I\01-Anderson\SR061

Region I\01-Anderson\SR071

Region I\01-Anderson\SR116

Region I\01-Anderson\SR116\001-40L

Region I\01-Anderson\SR116\002-00L

Region I\01-Anderson\SR116\002-60L

Region I\01-Anderson\SR116\002-70L

Region I\01-Anderson\SR116\002-80L

Region I\01-Anderson\SR116\003-60L

Region I\01-Anderson\SR116\003-70L

Region I\01-Anderson\SR116\004-50L

Region I\01-Anderson\SR116\005-30L

Region I\01-Anderson\SR116\005-40L

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Region I\01-Anderson\SR116\005-60L

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Region I\01-Anderson\SR116\006-70L

Region I\01-Anderson\SR116\006-70R

Region I\01-Anderson\SR116\007-20R

Region I\01-Anderson\SR116\007-70L

Region I\01-Anderson\SR116\008-00L

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Region I\01-Anderson\SR116\016-50L

Region I\01-Anderson\SR116\018-80R

Region I\01-Anderson\SR330

Region I\01-Anderson\SR330\001-30L

Region I\01-Anderson\SR330\001-60R

Region I\01-Anderson\SR330\002-20R

Region I\05-Blount

Region I\05-Blount\SR033

Region I\05-Blount\SR035

Region I\05-Blount\SR073

Region I\05-Blount\SR115

Region I\07-Campbell

Region I\07-Campbell\I0075

Region I\07-Campbell\SR009

Region I\07-Campbell\SR071

Region I\07-Campbell\SR090

Region I\07-Campbell\SR116

Region I\07-Campbell\SR297

Region I\10-Carter

Region I\10-Carter\SR037

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Region I\34-Hancock\SR066

Region I\37-Hawkins

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Region I\46-Johnson

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Region I\46-Johnson\SR133

Region I\46-Johnson\SR159

Region I\46-Johnson\SR167

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Region I\47-Knox\I0075

Region I\47-Knox\SR033

Region I\47-Knox\SR071

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Region I\62-Monroe\SR165

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Region I\65-Morgan\SR029

Region I\65-Morgan\SR062

Region I\65-Morgan\SR116

Region I\65-Morgan\SR298

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Region I\73-Roane\SR001

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Region I\82-Sullivan\SR001

Region I\82-Sullivan\SR034

Region I\82-Sullivan\SR036

Region I\82-Sullivan\SR044

Region I\82-Sullivan\SR093

Region I\82-Sullivan\SR347

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Region I\82-Sullivan\SR435

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Region I\86-Unicoi\SR081

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Region II\08-Cannon\SR053

Region II\14-Clay

Region II\14-Clay\SR052

Region II\14-Clay\SR053

Region II\16-Coffee

Region II\16-Coffee\I0024

Region II\16-Coffee\SR002

Region II\18-Cumberland

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Region II\21-DeKalb\SR141

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Region II\25-Fentress\SR052

Region II\25-Fentress\SR085

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Region II\26-Franklin\SR016

Region II\26-Franklin\SR056

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Region II\31-Grundy\SR002

Region II\31-Grundy\SR050

Region II\33-Hamilton

Region II\33-Hamilton\SR002

Region II\33-Hamilton\SR008

Region II\33-Hamilton\SR058

Region II\33-Hamilton\SR148

Region II\44-Jackson

Region II\44-Jackson\SR056

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Region II\71-Putnam\I0040

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Region II\93-White\SR026

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Region III\41-Hickman\SR438

Region III\50-Lawrence

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Region III\51-Lewis

Region III\51-Lewis\SR099

Region III\52-Lincoln

Region III\52-Lincoln\SR010

Region III\56-Macon

Region III\56-Macon\SR056

Region III\56-Macon\SR262

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Region III\60-Maury\SR099

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Region III\83-Sumner\SR376

Region III\94-Williamson

Region III\94-Williamson\SR100

Region IV

Region IV\20-Decatur

Region IV\20-Decatur\SR100