LANDSLIDE INVENTORY MAP OF THE SUNCREST DEVELOPMENT, DRAPER, UTAH

Submitted to:
Mr. Jeff Anderson
SunCrest Development Corp.
2021 East Village Green Circle
Draper, UT 84020

Prepared by:
Dr. James P. McCalpin
GEO-HAZ Consulting, Inc.
P.O. Box 837
Crestone, CO 81131

GEO-HAZ Project #2082
Date: Nov. 30, 2003

Table of Contents

1. EXECUTIVE SUMMARY 3
2. INTRODUCTION 4
   - 2.1 Purpose and Scope of Study 4
   - 2.2 Acknowledgements....................5
3. GEOLOGIC SETTING 5
   - 3.1 Stratigraphy....................5
   - 3.2 Structure....................12
   - 3.3 Previous Landslide Mapping 12
4. LANDSLIDE INVENTORY MAPPING....................13
   - 4.1 Methods....................13
     - 4.1.1 Photogeologic Mapping....................13
     - 4.1.2 Landslide Classification System....................14
   - 4.2 Results....................15
     - 4.2.1 Relict Landslides....................18
     - 4.2.2 Old Landslides 20
     - 4.2.3 Mature-Old Landslides 20
     - 4.2.4 Mature Landslides....................22
     - 4.2.5 Young Landslides 22
5. IMPLICATIONS OF LANDSLIDE INVENTORY MAPPING TO ASSESSING SLOPE STABILITY HAZARDS....................23
   - 5.1 Reactivation Potential of Currently Dormant Landslides....................23
   - 5.1 Landslide A....................23
   - 5.2 Landslide B 24
   - 5.3 Landslide C 24
   - 5.4 Landslide D....................24
   - 5.5 Landslide E 24
   - 5.6 Landslide F....................24
6. CONCLUSIONS AND RECOMMENDATIONS 25
7. LIMITATIONS....................25
8. REFERENCES 26

Appendix 1; Digitization of Plate 1 28

Appendix 2; Statistics of landslide deposit polygons on the Landslide Inventory Map........29

1. EXECUTIVE SUMMARY

About half of the 2500-acre Suncrest Development is underlain by landslide deposits of various ages. These landslides lie mainly in a band of weathered Tertiary volcanic rocks that underlies the central part of the east Traverse Range, and that is less resistant to erosion than the bedrock formations to the east and west. The weakness of the volcanic rocks and their tendency to landslide has led to formation of a landscape with relatively gentle slopes, compared to slopes developed on Paleozoic sandstones to the west and Tertiary alluvial fan deposits on the east. Thus, while landsliding processes operating over geologic time spans made possible a subdivision at the top of this mountain range, they also pose a possible threat if landslides begin moving again in the future in developed areas.

Of the 55 landslide deposits mapped, 15 are classed as old or relict, and it is considered unlikely that these landslides will reactivate in the present climatic regime. In contrast, the remaining 40 deposits are classed as young or mature, and are thought to be capable of reactivation. Residential development is planned on mature or young landslides in seven areas, lettered Slide A through Slide F. For each of these areas a geotechnical stability analysis is recommended, based on geotechnical boreholes and material testing.

If the stability analyses of Slides A through F predict stability in post-development conditions, then no further stability analysis is recommended for old or relict landslides in areas of proposed development. Conversely, if the stability analyses of those landslides predict instability in post-development conditions, then not only must mitigation alternatives be pursued, but further stability analysis is recommended for old or relict landslides in areas of proposed development.

2. INTRODUCTION

2.1 Purpose and Scope of Study

The purpose of this study was twofold. The first goal was to make a Landslide Inventory Map of the ca. 2500-acre planned and existing Suncrest Development and its immediate vicinity, in Draper, Utah (Fig. 1). The second goal was to recommend a program of slope stability investigations for those landslides that were judged to pose a risk to existing or future residential development.

The Landslide Inventory Map portrays historic landslides in and around the development, which range widely in age, size, and type of movement. Landslides were classified by inferred age and movement type, and generally, it is assumed that the younger the landslide, the higher its potential for future reactivation. The Landslide Inventory Map identified fairly young landslides in 6 areas where future development is planned. For each of the these 6 areas we recommend a standard slope stability analysis based on on-site geotechnical drilling and trenching data.

The justification for landslide inventory mapping is given by Soeters and van Westen (1996, p. 130*): “A reliable landslide inventory defining the type and activity of all landslides, as well as their spatial distribution, is essential before any analysis of the occurrence of landslides and their relationship to environmental conditions is undertake.”… “Such mass movement inventory maps are the basis for most other landslide hazard zonation techniques.”(p. 134)*

Fig. 1. Location of the Suncrest Development, situated atop the east Traverse Mountains south of Salt Lake City, Utah.

2.2 Acknowledgements

I thank Alan Taylor of PSI for providing office space and consultation during my visit to Salt Lake City. Craig Nelson of Western GeoLogic provided aerial photographs of the project site and discussed previous work. Bob Biek of the Utah Geological Survey provided copies of the in-progress geologic map of the Lehi quadrangle, and discussed bedrock geology and landsliding in the Traverse Mountains. Frank Ashland of the Utah Geological Survey described recent episodes of landslide reactivation in central Utah and their causes. Darlene Batatian of Salt Lake County lent me historical aerial photographs of the Traverse Mountains. Jeff Anderson and John Bowman of SunCrest Development provided logistical support. Janet Jenkins and Jacob Jensen of Thompson-Hysell assisted in digitizing and georeferencing the landslide inventory map.

3. GEOLOGIC SETTING

The east Traverse Mountains are a linear ridge about 5 miles long and 2.5 miles wide that extends west-southwest off the Wasatch Mountains and separates (along with the west Traverse Mountains) Salt Lake Valley on the north from Utah Valley on the south. The western part of the east Traverse Mountains is in the Jordan Narrows 7.5' quadrangle and the central and eastern parts are in the Lehi 7.5' quadrangle. According to Machette (1992) and Biek (2003a, 2003b), the east Traverse Mountains are underlain (from west to east) by the Oquirrh Group (Permo-Pennsylvanian), Tertiary volcanics (Oligocene), and Tertiary sedimentary rocks (Oligocene? to Pliocene?) (Fig. 2, Table 1). In general, the contacts between these three geologic units are unconformities that dip gently east, toward the Wasatch Fault. In places, however, the units are juxtaposed across faults, particularly on the southern margin of the east Traverse Mountains. The part of the east Traverse Mountains underlain by Tertiary volcanic rocks is typified by gentler slopes than to the west and east, and this area forms the core of the Suncrest Development.

3.1 Stratigraphy

The Oquirrh Group in the east Traverse Mountains is “almost entirely orthoquartzite and calcareous sandstone with minor sandy limestone” (Biek, 2003b, p.14). Elsewhere in northern Utah the Group is resistant to erosion and form well-preserved outcrops. In the east Traverse Mountains, however, the sandstone is”typically highly fractured, intensely brecciated, or locally pulverized” (Biek, 2003b). Due to this brecciated and fractured nature, bedding is difficult to discern, and good outcrops are rare (Robert Biek, personal communication, 2003). Those outcrops where bedding can be discerned yield erratic strikes and dips. Due to the poor outcrops, Biek (2003b) mapped this area as “Oquirrh Group, undivided” (map unit lPou on Fig. 3) rather than trying to define a particular formation within the Oquirrh Group, but he does speculate that “most of lPou probably belongs to the Butterfield Peaks Formation.”

The central part of the Traverse Mountains, including most of the Suncrest Development, is underlain by Tertiary volcanic rocks of inferred Oligocene age. According to Biek (2003b), these rocks include “volcanic breccias, flows, and tuffs which are impractical to map separately throughout most of the Traverse Mountains due to poor exposures; classified as borderline dacite, trachydacite, trachyandesite, and andesite…; flows, some of which could be welded tuffs, are more common in the east Traverse Mountains…; probably derived from volcanic centers in the west Traverse Mountains, including Shaggy Peak, a rhyolitic plug that yielded a K-Ar age of 33.0±1.0 Ma [Ma= 1 million years].” Biek (2003b) also notes that the Tertiary volcanic rocks are highly weathered, which may explain why natural outcrops are so scarce. He notes the rock is “locally extensively hydrothermally altered in the east Traverse Mountains, including fracture-controlled silicified zones up to 400 feet (120 m) wide that grade outward to kaolinized and oxidized volcanic rock….”. According to Biek (personal commuication, 2003), these volcanic rocks were erupted onto a landscape underlain by the Oquirrh Group that contained some relief (valleys and hills), so the flows and tuffs buried a preexisting topography in a complex succession of channels and sheets.

Roadcuts along the southern margin of the 80-acre inholding (rectangle in southern lobe of Polygon #18) show the complex and heterogenous nature of the volcanic rock (Fig. 4). Several volcanic and volcaniclastic rock types are juxtaposed along subvertical contacts, some of which appear to be shear zones.

Based on Biek’s and my observations, much of the Tertiary volcanic rock has been chemically and physically altered subsequent to its formation. For example, the variegated green white, and red gritty clays exposed in roadcuts are probably altered volcanic ashes that initially contained no clay, but have developed clay minerals from alteration and hydration of silicates and glass. Most artificial cuts in the Suncrest Development (e.g., Fig. 4) were made by earthmoving machinery without blasting, showing that the rock mass as a whole has low strength. Due to the weak rock strength, natural outcrops are rare, and thus Biek did not attempt to subdivide the volcanic rocks into subunits or into individual falls or flows.

The eastern part of the Traverse Mountains is underlain by coarse-grained sedimentary rocks of late Tertiary age. Biek (2003b) terms these deposits “alluvial fan deposits” whereas Machette (1992) termed them “Tertiary sedimentary rocks.” These rocks are weakly cemented sandstones and conglomerates derived from erosion of the Wasatch Mountains as they began to develop in the middle Tertiary. Due to the weak cementation of these rocks outcrops are rare, but those few show that beds generally dip east toward the Wasatch Fault at 10-20°.

Quaternary (unconsolidated) deposits are relatively rare in the Traverse Mountains, but Biek (2003b) maps a considerably larger area of these deposits within the Suncrest Development than did Machette (1992). For example, the only large area of surficial deposits that Machette (1992) mapped in Suncrest covers the landslide complex on the north-central margin of the development (his map unit “clso” on Fig. 2). In contrast, Biek mapped 10 different types of Quaternary deposits in the development (Fig. 3). The most areally extensive of his units is Qmsy and Qmso, younger and older landslides, respectively (these are discussed later). The next most widespread unit is Qac, colluvium and alluvium. These slopewash and creep deposits occur mainly on nearly flat areas (often back-rotated areas at the heads of landslides) at the bases of steep slopes (often headscarps). Biek (2003b) also mapped artifical fills (Qf) and mixed cuts and fills (Qfd) as they existed at Suncrest in May 2002.

Table 1. Description of geologic units at Suncrest Development, as mapped by Biek, 2003b (correlates with Fig. 3).

Abbreviation	Geologic unit	Age	Description
Qf	Artificial fill	historic	Fill used to create level building areas
Qfd	Disturbed land	historic	Complex mix of very large cuts and smaller areas of fill in deeply weathered volcanic rocks
Qafy	Younger undifferentiated alluvial fan deposits	Holocene to upper Pleistocene	Clay to boulder size sediment deposited by debris flows at the mouths of drainages
Qafo	Older alluvial fan deposits	upper Pleistocene	
Qafb	Alluvial fan deposits related to the Bonneville phase of Lake Bonneville	upper Pleistocene	
Qac	Alluvial and colluvial deposits	Holocene to upper Pleistocene	Clay to boulder size sediment deposited in swales and small drainages by fluvial, slopewash, and creep processes
Qaco		upper Pleistocene	
Qc	Colluvial deposits	Holocene to upper Pleistocene	Locally derived sediment deposited by slopewash and soil creep
Qmsy	Younger landslide deposits	Holocene to upper Pleistocene	Very poorly sorted clay to boulder size material
Qmso	Older landslide deposits	upper Pleistocene	
Qmt	Talus deposits	Holocene to upper Pleistocene	Angular cobbles and boulders deposited by rockfall
Qmtc	Talus and colluvium	Holocene to upper Pleistocene	Angular cobbles and boulders plus finer matrix deposited by rockfall and slopewash
Taf	Alluvial fan deposits	Middle Oligocene to Pliocene	conglomerate
Tv	Volcanic rocks of Traverse Mountains, undifferentiated	Oligocene	volcanic breccias, flows, and tuffs of dacitic to andesitic composition
Tvpd	Pebble dikes	Oligocene	Dikelike masses intruded into volcanic rocks, composed of angular pebbles
lPou	Oquirrh Group, undivided	Upper to middle Pennsylvanian	Orthoquartzite, sandy limestone

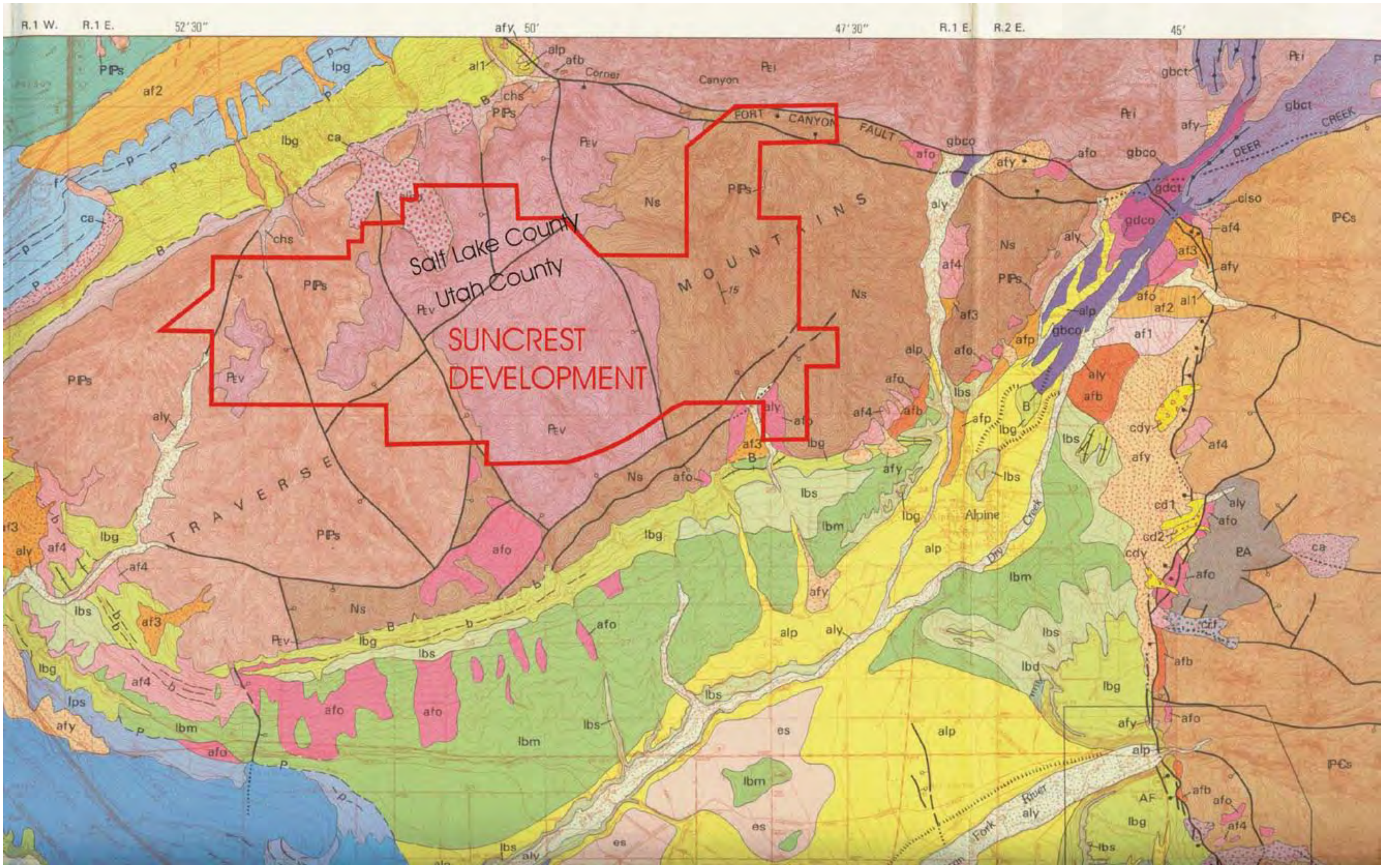


Fig. 2. Generalized geologic map of the Suncrest Development. Geology from Machette, 1992.

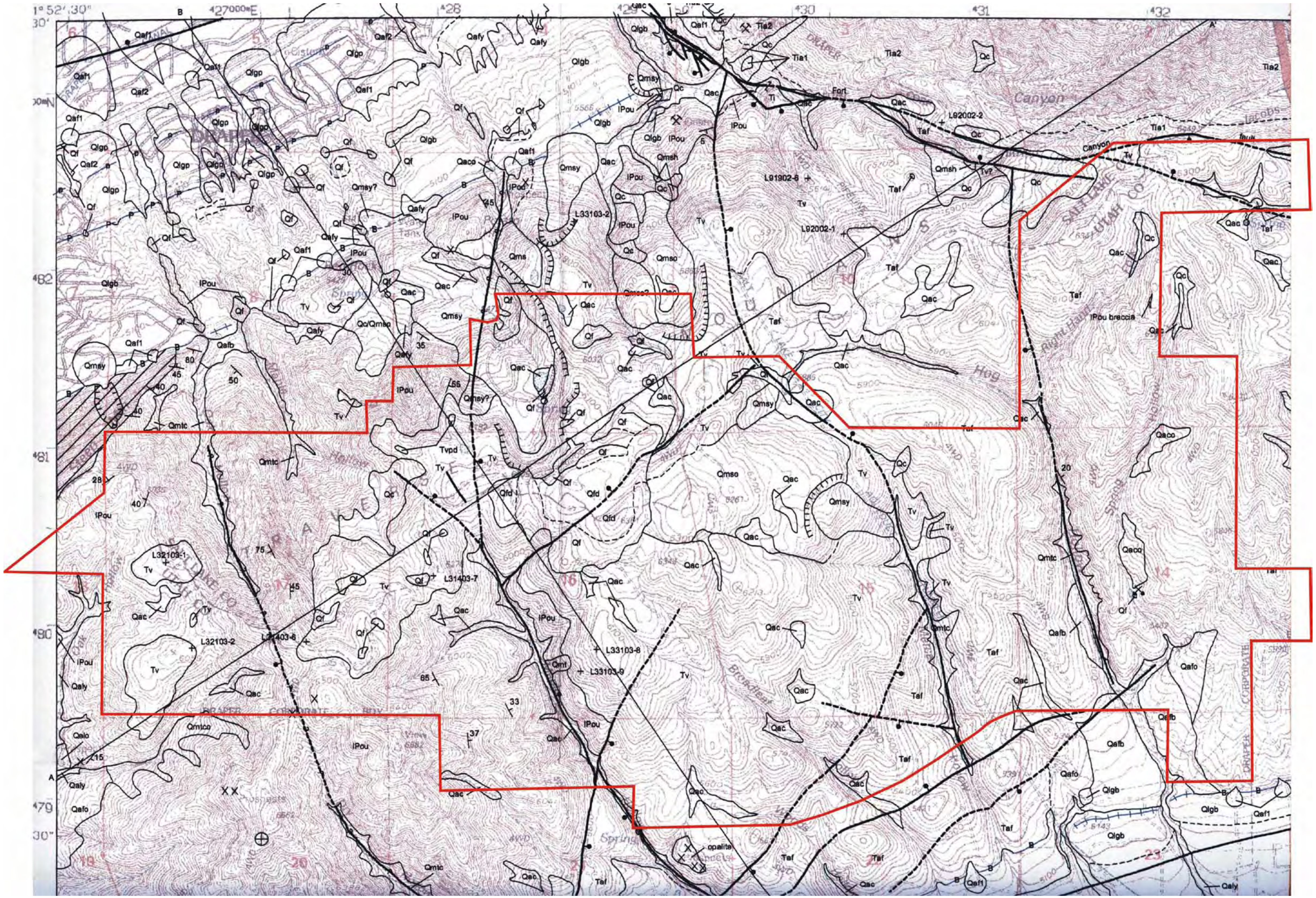


Fig. 3. Portion of Biek’s (2003b) geologic map covering the Suncrest Development (outlined in red). Original scale= 1:24,000. Section lines (thin red lines) are 1 mile apart. Units are explained in Table 1.

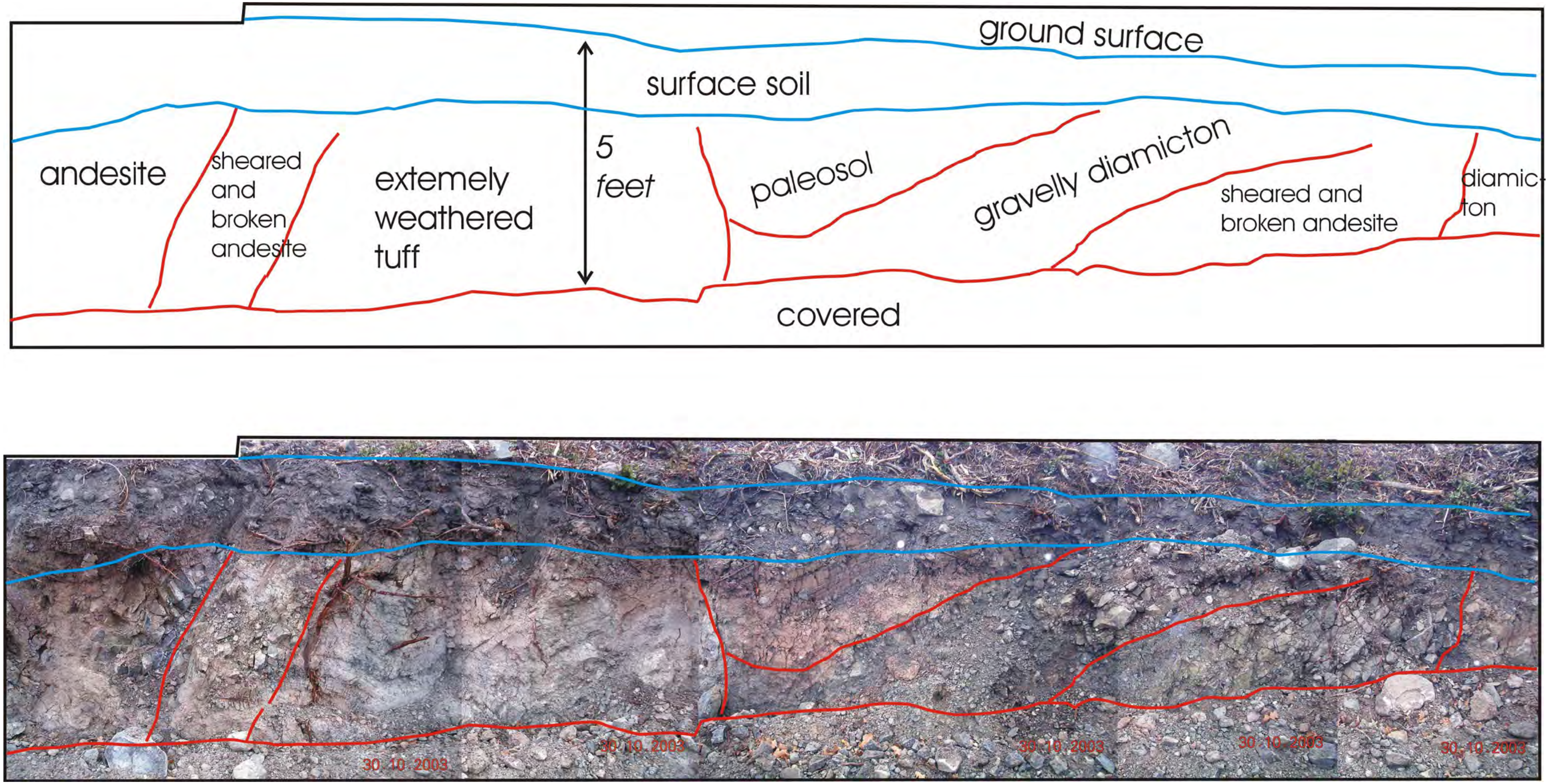


Fig. 4. Photo-mosaic of a south-facing roadcut on the southern margin of the 80-acre inholding in central Suncrest. Lower panel, annotated photomosaic; upper panel, interpretation.

3.2 Structure

The east Traverse Mountains are cut by a rectilinear network of broadly-spaced normal faults that trend either WNW (perpendicular to the ridge axis) to WSW (parallel to the ridge axis) (Figs. 2, 3). The net displacement on these faults is relatively small (tens to hundreds of feet) relative to the Wasatch fault, which separates the Traverse Mountains from the Wasatch Mountains. Members of both sets of faults cut the late Tertiary sedimentary rocks (unit Taf), so they have been active subsequent to Miocene to Pliocene? Time, but none of them are classified as active faults by either Salt Lake County or Utah County (e.g., Nelson and Bryant, 2002). However, the Fort Canyon fault strand of the Wasatch fault zone does intersect the extreme northeastern corner of the development. This small area lies within the Salt Lake County Special Study Area for surface rupture, according to the official zoning map (Nelson and Bryant, 2002), and mainly coincides with landslide deposit 21 (Fig. 5). However, analysis of active faulting hazards is beyond the scope of this study.

3.3 Previous Landslide Mapping

The east Traverse Mountains were covered by several previous landslide maps. Harty (1991) mapped landslides over the entire State, using previous mapping, aerial photographs, and historic accounts. Her map includes 2 small (less than 2000 feet long), deep-seated (thicker than 10 feet), historic (post-1847 A.D.) landslides in Hog Hollow. Due to the scale of the map (1:500,000) these landslides are represented schematically by small circles. Later, Harty (1992) published a landslide map of the Provo 30’ by 60’ quadrangle at a scale of 1:100,000. In the east Traverse Mountains she again identified only 3 small historic landslides in Hog Hollow, plus a larger landslide complex east of Suncrest.

Simultaneously, Machette (1992) published a map of surficial deposits along the Wasatch Front that included landslide as well as other Quaternary deposits. Although this map was field checked in many places along the Wasatch fault and in the urbanized valleys, Machette did no field checking within the (future) Suncrest Development (Mike Machette, personal communication, 2003). Machette mapped the large landslide complex north of the central part of Suncrest (deposits 10-13 on Plate 1), as well as a separate slump (deposit 15 on Plate 1). He did not map the small historic landslides mapped by Harty (1991, 1992), nor did she map the large landslides that he recognized.

After a hiatus of 11 years, Biek (2003b) published a 1:24,000-scale geologic map of the Lehi quadrangle, which contains Suncrest. Biek’s map contains 7 landslide deposits partly or wholly within the Suncrest Development. Four landslides are at or near the north-central boundary of the development, with the western 2 being the same as Machette’s (1992) and the eastern 2 being previously unmapped. More importantly, Biek mapped the crest of the ridge as a large, older landslide (Qmso) flanked by two smaller, younger landslides (Qmsy). These landslides combined cover about 150 acres in the center of the development.

Finally, Nelson (2003) wrote a letter report to Suncrest Development that identified the easternmost Qmsy deposit mapped by Biek (2003b) in Mercer Hollow, but enlarged it to either side.

4. LANDSLIDE INVENTORY MAPPING

4.1 Methods

Landslide inventory maps are typically *"based on interpretation of aerial photographs, ground surveys, and data bases of historical occurrences of landslides in an area."* Soeters and van Westen (1996, p. 134). Due to the short time frame for this study, airphoto interpretation was the main source of data. However, published geologic and landslide mapping was examined (cited previously), and the site was examined briefly in the field.

4.1.1 Photogeologic Mapping

The main technique for mapping landslides at SunCrest was viewing stereoscopic aerial photographs. I followed the standard methodology as outlined in Soeters and van Westen (1996) and Keaton and DeGraff (1996). Table 1 list the photographs examined.

Table 2. Aerial Photographs Examined. The 1937 photographs were the main source of information.

Source of Photographs	**Date of Photographs; Mission Abbreviation**	**Roll and Frame Numbers**	**Type**	**Scale**
National Archives[1]	9-21-1937 AAL	4-30 to 4-33; 4-41 to 4-44	B&W	1:20,000
U.S. Forest Service[1]	5-27-1958 AAL	12V-116 to 12V-120; 16V-22 to 16V-26;	B&W	1:10,000
U.S. Forest Service[1]	10-15-1958 AAL	35V-93 to 35V-98	B&W	1:10,000
Olympus Aerial Surveys[2]	7-22-1972 CVX	3MM-4 to 3MM-6	B&W	1:24,000
Olympus Aerial Surveys	3-12-1992 92013	2-22 to 2-24	B&W	1:24,000
Olympus Aerial Surveys	2-19-1996 96013	2-18 to 2-20	B&W	1:24,000
Olympus Aerial Surveys	3-25-1997 97013	2-18 to 2-20	B&W	1:24,000
Olympus Aerial Surveys	2003 203002	6A-01 to 6A-04	color	1:24,000

[1] copies obtained from the Salt Lake County Geologist's office.
[2] copies obtained from Western GeoLogic, Salt Lake City, UT.
[3] copies obtained from Olympus Aerial Surveys, Salt Lake City, UT.

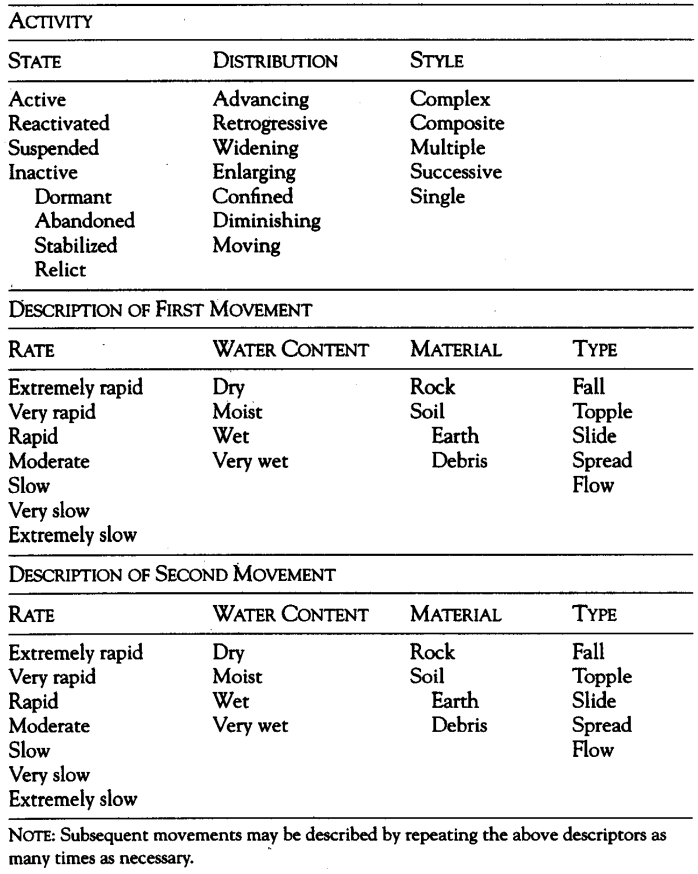
Landslide boundaries interpreted from the airphotos were drawn on a mylar overlay attached to each photograph, using only the central part of the photograph where relief displacement was minimized. The eroded scarps from which the landslide mass detached, as well as interpreted tension fractures (troughs) were also mapped. Line symbols with arrows show the tracks of shallow debris flows between the initiating debris slide (YDS) and the site of deposition on an alluvial fan (YDF).

The mylar overlays were then detached and enlarged to 1:12,000 scale on a photocopy machine. All linework was then transferred manually on a light table from the enlarged overlays to the 1:12,000-scale base map from Thompson-Hysell entitled "Suncrest 1:12,000 Landslide Inventory Map" (filename K:\SUNCREST\MAPS\EXHIBITS\LANDSLIDE INVENT-10-23-03.dwg). This hard copy map was then hand-colored and used as an informal exhibit at the meeting of October 30, 2003 at the Utah Geological Survey.

4.1.2 Landslide Classification System

Each landslide deposit and scarp was classified using the Unified Landslide Classification System of Keaton and DeGraff (1996). In order to use this classification, one must classify the geologic material that comprises the landslide (rock, soil, earth, or debris; see Table 3-2), the type of movement (fall, topple, slide, spread, flow; see Table 3-2), and the age or activity of the landslide. Table 3-2 shows the categories for the first two parameters, from Cruden and Varnes (1996, p. 38).

Table 3-2
Glossary for Forming Names of Landslides



ACTIVITY			
STATE	DISTRIBUTION	STYLE	
Active	Advancing	Complex	
Reactivated	Retrogressive	Composite	
Suspended	Widening	Multiple	
Inactive	Enlarging	Successive	
Dormant	Confined	Single	
Abandoned	Diminishing		
Stabilized	Moving		
Relict			
DESCRIPTION OF FIRST MOVEMENT			
RATE	WATER CONTENT	MATERIAL	TYPE
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very wet	Debris	Spread
Slow			Flow
Very slow			
Extremely slow			
DESCRIPTION OF SECOND MOVEMENT			
RATE	WATER CONTENT	MATERIAL	TYPE
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very wet	Debris	Spread
Slow			Flow
Very slow			
Extremely slow			

NOTE: Subsequent movements may be described by repeating the above descriptors as many times as necessary.

Classifying the age (or most recent activity) of a landslide from its appearance on an aerial photograph is typically based on the sharpness, or "freshness" of component landforms (headscarps, toes, internal cracks, etc.). Table 9-1 shows the age classification commonly used in landslide inventory mapping in the Rocky Mountains (from Keaton and DeGraff, 1996, after McCalpin, 1984), and Fig. 4 shows corresponding diagrams.

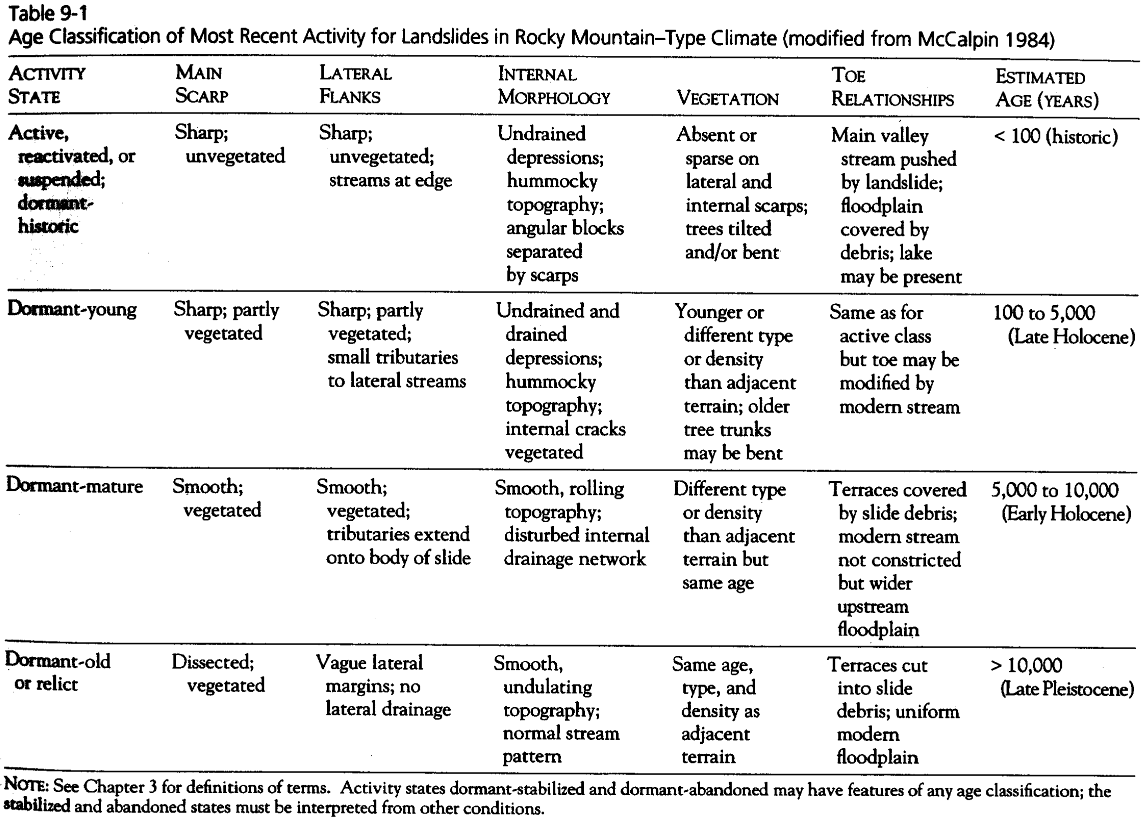


Table 9-1

Age Classification of Most Recent Activity for Landslides in Rocky Mountain–Type Climate (modified from McCalpin 1984)

ACTIVITY STATE	MAIN SCARP	LATERAL FLANKS	INTERNAL MORPHOLOGY	VEGETATION	TOE RELATIONSHIPS	ESTIMATED AGE (YEARS)
Active, reactivated, or suspended; dormant-historic	Sharp; unvegetated	Sharp; unvegetated; streams at edge	Undrained depressions; hummocky topography; angular blocks separated by scarps	Absent or sparse on lateral and internal scarps; trees tilted and/or bent	Main valley stream pushed by landslide; floodplain covered by debris; lake may be present	< 100 (historic)
Dormant-young	Sharp; partly vegetated	Sharp; partly vegetated; small tributaries to lateral streams	Undrained and drained depressions; hummocky topography; internal cracks vegetated	Younger or different type or density than adjacent terrain; older tree trunks may be bent	Same as for active class but toe may be modified by modern stream	100 to 5,000 (Late Holocene)
Dormant-mature	Smooth; vegetated	Smooth; vegetated; tributaries extend onto body of slide	Smooth, rolling topography; disturbed internal drainage network	Different type or density than adjacent terrain but same age	Terraces covered by slide debris; modern stream not constricted but wider upstream floodplain	5,000 to 10,000 (Early Holocene)
Dormant-old or relict	Dissected; vegetated	Vague lateral margins; no lateral drainage	Smooth, undulating topography; normal stream pattern	Same age, type, and density as adjacent terrain	Terraces cut into slide debris; uniform modern floodplain	> 10,000 (Late Pleistocene)

NOTE: See Chapter 3 for definitions of terms. Activity states dormant-stabilized and dormant-abandoned may have features of any age classification; the **stabilized** and abandoned states must be interpreted from other conditions.

For this study, we have used age classes of young, mature, old, and relict. The first 3 classes correspond to those in Table 9-1. The relict class is even older than the old class, and includes landslide deposits that can no longer be confidently associated with a known scarp or source area. Evidently the topography of the area has changed sufficiently since the deposition of relict slides, that some or all of the source area has been eroded away.

As pointed out by Ashland (2003), this type of photogeologic age classification, although the current standard of practice in landslide inventory mapping (Keaton and DeGraff, 1996), has one weakness. It assumes that the initial movement of the landslide was rapid, and after it stopped, the landslide features have been progressively modified by erosion over geologic time. A notable exception is some slow-moving landslides that may continue to creep at slow rates and yet retain the smooth appearance of an older, rapid landslide. This is particularly true of flow-type landslides, such as earthflows (e.g., MEF on the Landslide Inventory Map). In such cases, the photogeologic age class may be Mature or Old, when in fact the slide may have experienced much more recent periods of creeping movement (Active or Young). However, only a few landslides at Suncrest appear to be flow-type failures, so this drawback may not be widely relevant here.

For some land uses such as roadways, the ambiguity about a possible young creep component is not so critical, because any landslide debris creeping into a road right-of-way can be dealt with by routine road and ditch maintenance. For residential developments with houses and buried utilities, however, the tolerance for creep movement is lower. Therefore, the reader should understand that the age classification used in this landslide inventory cannot detect, nor preclude, a small component of young creep movement on landslides in any of the age categories, although it is less likely in the older age categories.

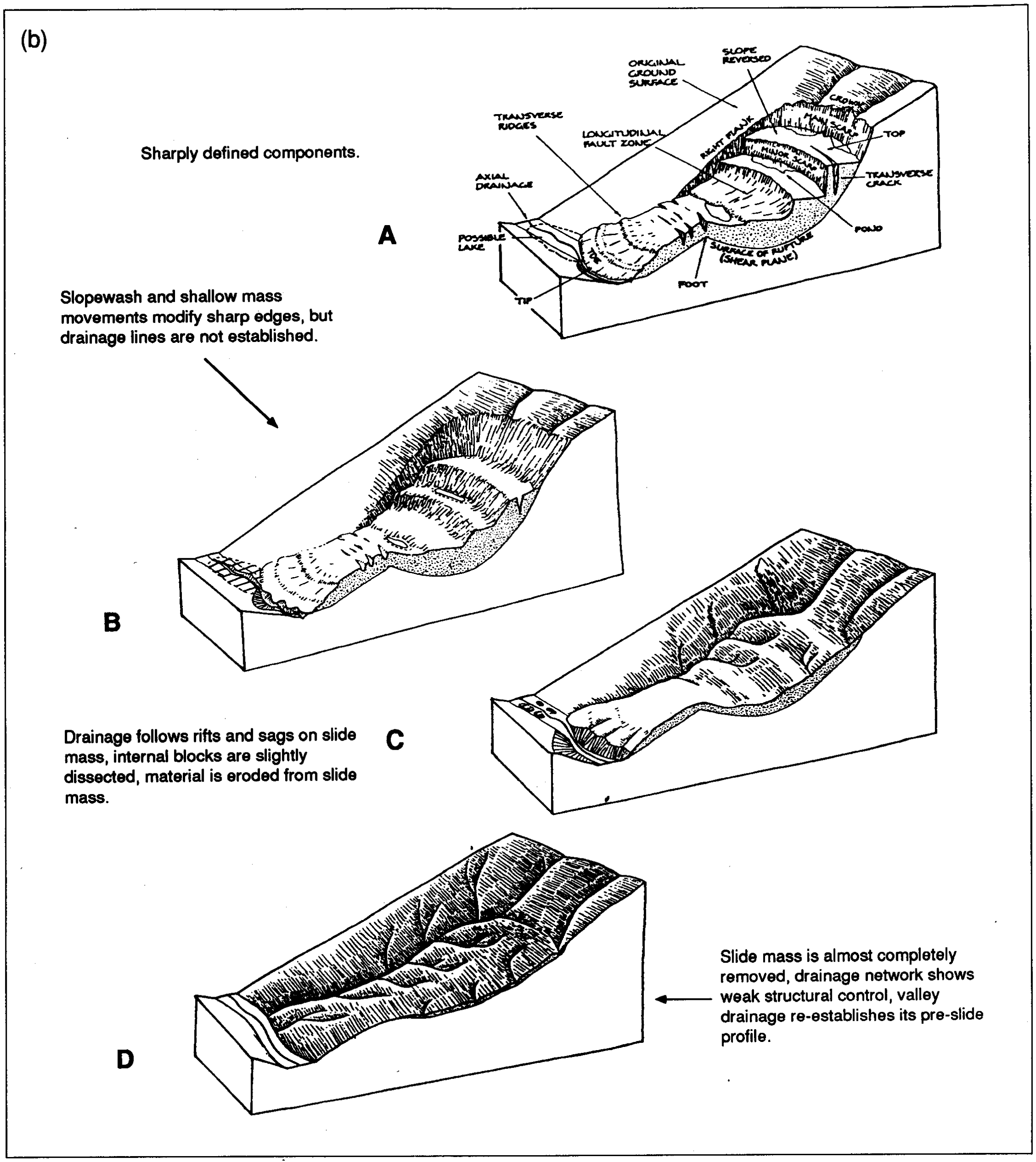


Fig. 4. Schematic diagrams showing active (A), young (B), mature (C), and old (D) landslides. From Keaton and DeGraff (1996), after McCalpin (1984).

Table 9-2 shows the abbreviations used in the Unified Landslide Classification System of Keaton and DeGraff (1996), and also used on the Landslide Inventory Map (Fig. 5 and Plate 1). Plate 1 was created by digitizing the hand-colored map described previously, as explained in Appendix 1.

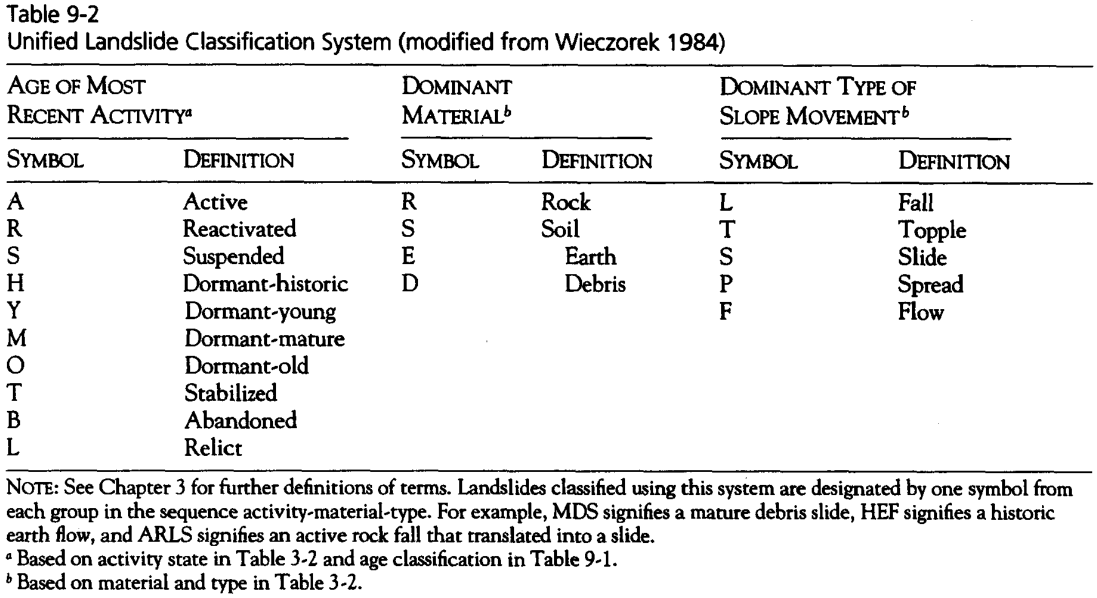


Table 9-2
Unified Landslide Classification System (modified from Wieczorek 1984)

AGE OF MOST RECENT ACTIVITY[a]		DOMINANT MATERIAL[b]		DOMINANT TYPE OF SLOPE MOVEMENT[b]	
SYMBOL	DEFINITION	SYMBOL	DEFINITION	SYMBOL	DEFINITION
A	Active	R	Rock	L	Fall
R	Reactivated	S	Soil	T	Topple
S	Suspended	E	Earth	S	Slide
H	Dormant-historic	D	Debris	P	Spread
Y	Dormant-young			F	Flow
M	Dormant-mature				
O	Dormant-old				
T	Stabilized				
B	Abandoned				
L	Relict				

NOTE: See Chapter 3 for further definitions of terms. Landslides classified using this system are designated by one symbol from each group in the sequence activity-material-type. For example, MDS signifies a mature debris slide, HEF signifies a historic earth flow, and ARLS signifies an active rock fall that translated into a slide.

[a] Based on activity state in Table 3-2 and age classification in Table 9-1.

[b] Based on material and type in Table 3-2.

4.2 Results

The Landslide Inventory Map depicts 55 landslide deposits and their associated source areas, marked by headscarps and internal scarps (Fig. 5 and Plate 1). This number is much larger than that mapped by previous workers and requires some explanation. First, the workers cited previously were either not specifically looking for landslides (Machette, Biek), or did they not perform field checking in the development (Harty, Machette). Second, Harty and Machette were mapping at smaller scales (1:50,000 to 1:500,000) compared to this study (1:12,000 scale, based on 1:20,000 airphotos). Third, this study relies on 8 sets of aerial photographs spanning the period 1937-2003, whereas the other studies used one set. Fourth, this study had the advantage of being able to examine all the previous bedrock and landslide mapping. Fifth, I was able to examine open cuts at Suncrest that did not exist when the other workers (except Nelson, 2003) were field checking their maps. Due to these 5 factors, and my past experience in landslide inventory mapping (McCalpin, 1983, 1985), I was able to identify many geomorphic anomalies overlooked by previous workers, and to relate them to landslides deposits observed in short-lived artificial cuts.

Mapped landslide deposits cover a total of 1295 acres out of the total ~2500 acres of the Suncrest Development (Table 3, Appendix 2). The average size of the 55 landslide deposits is 23.9 acres, but individual landslides range in area from less than 1 acre to more than 400 acres. In general, the oldest landslides are the largest and the youngest landslides are smaller reactivations of older landslides.

Table 3. Statistics of landslide deposits, listed by age, material, and type. Numbers in the boxes represent, from top to bottom, the number (N) of landslide deposits in the class, the average size (in acres), and the total number of acres in the class.

Age	Material and Type					
	Debris (D)		Earth (E)		Rock (R)	
	Slide (S)	Flow (F)	Flow (F)	Slide (S)	Slide (S)	Flow (F)
Young (Y) N=23 avg. 2.4 ac total 52.3 ac	N=11 avg. 2.7 ac total 29.4 ac	N=11 avg. 1.9 ac total 20.8 ac			N=1 Total 2.3 ac	
Mature (M) N=16 avg.30.4 ac total 487 ac	N=1 total 2.3 ac		N=1 total 56.8 ac	N=1 total 23.5 ac	N=13 avg. 31.1 ac total 404.4 ac	
Mature-Old (MO)					N=1 total 40.3 ac	
Old (O) N=13 avg. 16.2 ac total 211.1 ac			N=1 total 20.3 ac		N=11 avg. 14 ac total 154 ac	N=1 total 36.8 ac
Relict (R) N=2 avg. 252 ac total 504 ac			N=2 avg. 252 ac total 504 ac			
TOTALS N=55 avg. 23.9 ac total 1,295 ac						

In the following 5 sections we describe the spatial distribution and characteristics of each age class of landslides. For ease of discussion the landslide deposits have been numbered from 1 to 53 (Fig. 5, Plate 1).

4.2.1 Relict Landslides (blue on Fig. 5 and Plate 1)

Number of Landslide Deposits: 2
Average Size: ....252 acres
Total Area Covered...504 acres

According to the landslide age classification of Cruden and Varnes (1996), "*Landslides that have clearly developed under different geomorphic or climatic conditions, perhaps thousands of years ago, can be called* ***relict****.*" We follow this naming convention for landslide deposits that are highly eroded and dissected, difficult to associate with a source area, and apparently "cut off" from their original source area by post-landsliding erosion.

There are only 2 relict landslide deposit polygons mapped (Polygons #18, #24 on Fig. 5 and Plate 1), but they are large, complex failures. The largest relict landslide (Polygon #18) lies astride the crestal ridge of the Traverse Mountains and the central part of the area currently developed as residential. Biek (2003b) mapped this deposit as "older landslide deposits". We digitized this landslide complex as a single large polygons for convenience, but it is probably composed of at least 3 independent lobes with different movement directions, and probably, different movement histories. Polygon #18 is bisected by a linear, northwest-facing scarp that coincides with a down-to-the-northwest normal fault mapped by Biek (2003b). This fault appears to form the southern limit of northward-directed landsliding, as if those landslides retrogressed upslope until they encountered the northwest-dipping fault, and then utilized its failure plane as their ultimate headscarp. For this reason I define a "breakaway line" along this fault (Fig. 5 and Plate 1), and its projection to the northeast, that marks the southern limit of northward-directed landsliding.

The southern lobe of Polygon #18 lies on the ridge crest and contains a network of curved west-facing (upslope-facing) scarps and troughs. The geometry of these scarps suggests that all of the slide except its southwestern corner was sliding to the east when it last moved. However, this may not be the direction in which the landslide initially moved, because there is a north-facing scarp at the southern margin of the deposit. The eastern part of this deposit has been reactivated in geologically more recent time by landsliding into the incised valley of Mercer Hollow (Polygons #29, 30, 31).

Altogether, this relict landslide does not have a clear source area, since it currently occupies the highest topography on the ridge. My interpretation is that the landslide deposit is so old (middle Pleistocene to latest Tertiary?), its source area has been eroded away. In contrast, Ashland (personal communication, 2003) speculated that the landslide is considerably younger, formed when the topography was essentially identical to today's, and is driven by failure into the incised valley of Mercer Hollow to the east. The problem with his scenario is twofold: (1) it doesn't explain why there is no east-facing headscarp on the western margin of the landslide, and (2) it requires that the landslide failure plane beneath the ridge summit be essentially flat, which eliminates any driving force for failure there.

Northwest of the scarp at the breakaway line, Polygon #18 has subdued topography and an indistinct downslope margin. The area between Polygon #18 and Polygons #12 and #16 may be part of a very deep-seated landslide block in bedrock, but if so, movement was not sufficient to create the distinctive hummocky topography that mark landslide terrain. In contrast, the northern part of Polygon #18 (between Polygons #16 and #19) contains enough scarps and trough to indicate clear movement to the north.

The other relict landslide deposit is Polygon #24, on the eastern side of Hog Hollow. This landslide is only revealed by three sets of curved to linear troughs and scarps, which are interpreted as incipient pull-apart zones. This landslide mass lies entirely within the Tertiary alluvial fan unit of Biek (2003b), which contains very few deep-seated landslides, especially south of the breakaway zone. Based on its geomorphology and bedrock source unit, this landslide is probably a nearly-intact block of bedrock that has moved downslope a few tens of feet on a deep failure plane, but not far enough to rubbilize the rock mas.

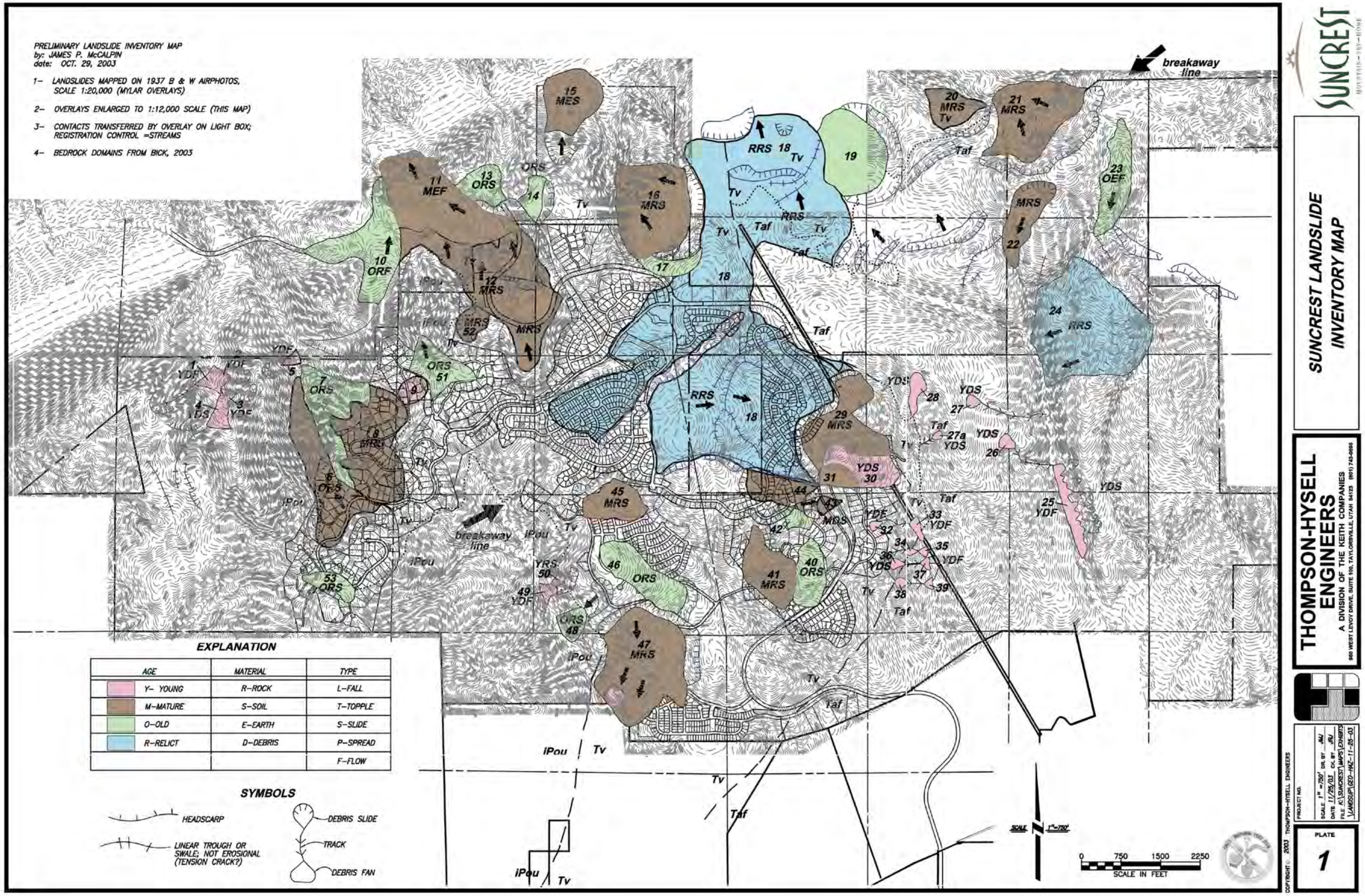


Fig. 5. Landslide Inventory Map. Polygon numbers correspond to those cited in the text and in Appendix 2.

4.2.2 Old Landslides (green on Fig. 5 and Plate 1)

Number of Landslide Deposits:	13
Average Size:	16.2 acres
Total Area Covered	211.1 acres

According to the landslide age classification of McCalpin (1984) for the Rocky Mountains, morphologically "old" landslides are characterized by *"smooth, undulating topography; vague lateral margins; no lateral drainage; and normal stream pattern [compared to adjacent terrane]."* Their source headscarps are easily recognized, although dissected by erosion. Generally, old landslides pre-date or are contemporaneous with the latest glacial advance in the Rocky Mountains (15,000-35,000 years old), or in the Bonneville basin, the Bonneville lake cycle (13,000-35,000 years old).

There are 13 old landslide deposit polygons mapped, 9 of which are adjacent to relict landslides or mature landslides (discussed in the next section). This pattern suggests that the old landslides are "left behind" parts of large landslide complexes, much of which was reactivated in more recent geologic time. For example, Polygons #10 and #13 are old landslides that flank the reactivated (mature) Polygons #11 and #12. Polygon #7 is the old, downslope half of a landslide, the upper half (Polygon #8) of which was reactivated as a mature landslide. In contrast, Polygons #17 and #46 are the upslope part of landslide complexes, the downslope parts of which (Polygons #16 and #47, respectively) were reactivated as mature landslides.

4.2.3 Mature-Old Landslides (brown on Fig. 5 and Plate 1)

Number of Landslide Deposits:	1
Total Area Covered	40.3 acres

A single deposit (Polygon #6) was mapped as transitional in age between old and mature. This deposit has sharper surface morphology than Polygon #7 (classed as old), but smoother morphology than Polygon #8 (classed as mature). This transitional classification may partly result from a component of earthflow-type movement in Polygon #6.

4.2.4 Mature Landslides (brown on Fig. 5 and Plate 1)

Number of Landslide Deposits:	16
Average Size:	30.4 acres
Total Area Covered	487 acres

According to the landslide age classification of McCalpin (1984) for the Rocky Mountains, morphologically "mature" landslides are characterized by *"smooth, rolling topography; tributary drainage along lateral margins; disturbed internal drainage network; floodplains wider upstream of toe."* Their source headscarps are easily recognized, although smoothed and eroded. Generally, mature landslides post-date the latest glacial advance in the Rocky Mountains (15,000-35,000 years old), or in the Bonneville basin, the Bonneville lake cycle (13,000-35,000 years old). McCalpin (1984) inferred that many of them dated from the early Holocene (5,000 to 10,000 years ago).

There are 16 mature landslide deposit polygons mapped, 12 of which are adjacent to relict landslides or old landslides (discussed previously). This pattern suggests that the mature landslides are reactivated parts of older, large landslide complexes.

4.2.5 Young Landslides (pink on Fig. 5 and Plate 1)

Number of Landslide Deposits:	23
Average Size:	2.4 acres
Total Area Covered	52.3 acres

According to the landslide age classification of McCalpin (1984) for the Rocky Mountains, morphologically "young" landslides are characterized by *"undrained and drained depressions; hummocky topography; internal cracks; sharp, partly vegetated lateral margins; different vegetation type and density than adjacent terrain."* Their source headscarps are easily recognized, sharp, and partly vegetated. Generally, young landslides have experienced movement in the late Holocene, in the past 100 to 5000 years.

There are 23 young landslide deposit polygons mapped, the largest number of any age category. However, due to their small size (average area 2.4 acres, compared to 16 acres for old landslides and 30 acres for mature landslides), their total area is only 52 acres. Eight of the landslide "deposits" (Polygons #26, 26, 27a, 28, 32, 34, 36, 38) are shallow debris slides (map unit YDS) at the heads of first-order drainages. Although some landslide debris appears to be left in these drainage heads, much of it liquefied upon failure and flowed down drainages as debris flows (lines with multiple arrows on Fig. 5 and Plate 1). Most debris flow material was deposited in debris-flow fans (map unit YDF) at the mouth of the drainage (Polygons #1, 2, 3, 4, 25, 33, 35, 37, 39, 49).

Three polygons (#9, 30, 47A) are deeper-seated, slump-type reactivations of deep-seated, mature landslides.

5. IMPLICATIONS OF LANDSLIDE INVENTORY MAPPING TO ASSESSING SLOPE STABILITY HAZARDS

5.1 Reactivation Potential of Currently Inactive Landslides

A Landslide Inventory Map is an important product, but its proper use and limitations must be understood. The Map shows only the locations of past landsliding [as far as is known, none of the mapped landslides are currently moving.] Generally, landslides that have moved once can potentially be reactivated, as shown by the widespread reactivation of Utah landslides during the 1983-84 wet period (Anderson et al., 1984), and again in 1998 (Ashland, 2003). For example, Cruden and Varnes (1996, p. 46) define a reactivated landslide as follows: *"A landslide that is again active after being inactive may be called* ***reactivated****. Slides that are reactivated generally move on preexisting shear surfaces whose [sic] strength parameters approach residual (Skempton, 1970) or ultimate (Krahn and Morgenstern, 1979) values."* The weaker the preexisting shear surfaces, the more likely future trigger mechanisms (rising groundwater, seismic shaking) will reactivate existing landslides rather than creating new ones.

As a first approximation, the probability of reactivation decreases with increasing landslide age, because: (1) ensuing erosion progressively alters the topography (and thus the driving forces) from its shape at the time of sliding, (2) dissection of the landslide mass drains it and thus lowers groundwater levels in the slide mass, and (3) eventually diagenetic changes and cementation can increase the strength of the landslide mass and/or its failure plane. This is assumed to be the case with the relict and old landslides mapped at Suncrest. Conversely, the topography of mature and young landslides has been scarcely altered with time, so a rise in groundwater levels to the level that caused the initial sliding could arguably initiate renewed sliding. Based on this logic, the landslides classed as young and mature in areas planned for future development should be subjected to a stability analysis. This analysis should determine whether the landslides will continue to be stable after proposed grading and the change in land use from vacant land to residential use. Both the static stability and stability under earthquake loading must be considered (Draper City, 2003).

There are four mature landslides in the areas slated for development in the near future. These are Polygons #29, 30 and 31 (Slide A), Polygon #41 (Slide B), Polygon #47 (Slide C), and Polygon #45 (Slide D). In addition, at some time in the future Polygon #8 (Slide E) and Polygon #6 (Slide F) will be developed. Each landslide should be subjected to a geotechnical static and dynamic stability analysis before development proceeds. The suggested locations of geotechnical boreholes mentioned in the following sections are shown on the cost proposal of October 31, 2003 from PSI, Inc. (Salt Lake City, Utah) to Mr. Bruce Baird, of Baird & Jones, Salt Lake City, Utah.

5.2 Landslide A

Landslide A is comprised of Polygons #29 (mature rock slide), #30 (young debris slide), and #31 (mature rock slide). The headscarp of landslide #29 extends into a residential area. The upper part of this landslide is bisected by a large divided roadway.

Future movement of this slide would disrupt the roadway and might undermine houses at and above the headscarp.

To analyze the stability of this landslide I recommend that 3 geotechnical boreholes be drilled along the long axis of Polygon 29. In addition, one borehole on the same alignment should be drilled into Polygon #18 upslope of the headscarp. One trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

5.2 Landslide B

Landslide B (Polygon #41) is a south-directed landslide (mature rock slide) south of the 80-acre inholding. To analyze the stability of this landslide I recommend that 3 geotechnical boreholes be drilled along the long axis of Polygon 41. In addition, one trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

5.3 Landslide C

Landslide C (Polygon #47) is a southwest-directed landslide (mature rock slide) on the south-central margin of the development. To analyze the stability of this landslide I recommend that 3 geotechnical boreholes be drilled along the long axis of Polygon 47. In addition, one trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

5.4 Landslide D

Landslide D (Polygon #45) is a south-directed landslide (mature rock slide) southwest of the 80-acre inholding. To analyze the stability of this landslide I recommend that 2 geotechnical boreholes be drilled along the long axis of Polygon 45. In addition, one trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

5.5 Landslide E

Landslide E (Polygon #8) is a northwest-directed landslide (mature rock slide) on the western margin of the development. To analyze the stability of this landslide I recommend that 3 geotechnical boreholes be drilled along the long axis of Polygon 8. In addition, one trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

5.6 Landslide F

Landslide F (Polygon #6) is a northwest-directed landslide (mature-old rock slide) on the western margin of the development. To analyze the stability of this landslide I recommend that 3 geotechnical boreholes be drilled along the long axis of Polygon 6. In addition, one trench should be dug into the lower part of the landslide, oriented down the fall line, to look for subsidiary shear planes.

6. CONCLUSIONS AND RECOMMENDATIONS

About half of the 2500-acre Suncrest Development is underlain by landslide deposits of various ages. These landslides lie mainly in a band of weathered Tertiary volcanic rocks that underlies the central part of the east Traverse Range, and that is less resistant to erosion than the bedrock formations to the east and west. The weakness of the volcanic rocks and their tendency to landslide has led to formation of a landscape with relatively gentle slopes, compared to slopes developed on Paleozoic sandstones to the west and Tertiary alluvial fan deposits on the east. Thus, while landsliding made possible a subdivision at the top of this mountain range, it also poses a possible threat if landslides begin moving again in the future.

Of the 55 landslide deposits mapped, 15 are classed as old or relict, and it is considered unlikely that these landslides will reactivate in the present climatic regime. In contrast, the remaining 40 deposits are classed as young or mature, and are thought to be capable of reactivation. In seven areas development is planned on mature or young landslides. For each of these areas a geotechnical stability analysis is recommended, based on geotechnical boreholes and material testing.

If the stability analyses of mature and young landslides predict stability in post-development conditions, then no further stability analysis is recommended for old or relict landslides in areas of proposed development. Conversely, if the stability analyses of mature and young landslides predict instability in post-development conditions, then not only must mitigation alternatives be pursued, but further stability analysis is recommended for old or relict landslides in areas of proposed development.

7. LIMITATIONS

The opinions presented in this report were developed from review of topographic and geologic maps, published geologic reports, aerial photographs, and site visits. Should additional surface, subsurface, or chemical data become available, the conclusions contained in this report should not be considered valid unless they are modified or approved in writing by our office.

A Landslide Inventory Map is an important product, but its proper use and limitations must be understood. The Map shows only the locations of past landsliding. Generally, landslides that have moved once can potentially be reactivated, and the probability of reactivation decreases with increasing landslide age. However, a Landslide Inventory Map is typically only the first product in a comprehensice Landslide Hazard Zonation study. For example, the Inventory map does not predict the susceptibility of future landsliding in areas where no past landslides have been mapped. To identify such areas one must perform a Landslide Susceptibility Analysis, as described by Soeters and van Westen (1996, p. 130-172). Such studies are beyond the scope of this investigation.

We believe that this investigation was conducted in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing under similar conditions in the locality of the site. No other warranty, expressed or implied, is made.

James P. McCalpin
Professional Geologist
Utah License No. 5526873

8. REFERENCES

Anderson, L.R., Keaton, J.R., Saarinen, T.F. and Wells, W.G. II, 1984, The Utah landslides, debris-flows, and floods of May and June, 1983: commission on Engineering and Technical Systems, National Research Council, National Academy Press, 96 p.

Ashland, F.X., 2003, Characteristics, causes, and implications of the 1998 Wasatch Front landslides, Utah: Utah Geological Survey, Special Study 105, 49 p.

Biek, R.F., 2003a, Interim geologic map of the Jordan narrows quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey, Open File Report OFR-415, 2 plates, scale 1:24,000.

Biek, R.F., 2003b, Interim geologic map of the Lehi quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey, Open File Report OFR-416, 2 plates, scale 1:24,000.

Blake, T.F., Hollingsworth, R.A. and Stewart, J.P. (eds.), 2002, Recommended procedures for implementation of DMG Special Publication 117, Guidelines for Analyzing and Mitigating Landslide Hazards in California: Southern California Earthquake Center, University of Southern California, Los Angeles, CA, 110 p. plus Appendix.

Cruden, D.M. and Varnes, D.J., 1996, Landslide types and process, in Turner, A.K. and Schuster, R.L. (eds.), Landslides-- investigation and mitigation: Transportation Research Board, Special Report 247, National Academy Press, Washington, DC, p. 36-75.

Draper City, 2003, Geologic Hazards Ordinance: Article 4 [Special Purpose and Overlay Zones], Chapter 9-18 of the Zoning Regulation, Draper City, Utah (draft).

Keaton, J.R. and DeGraff, J.V., 1996, Surface observation and geologic mapping, in Turner, A.K. and Schuster, R.L. (eds.), 1996, Landslides-- investigation and mitigation: Transportation Research Board, Special Report 247, National Academy Press, Washington, D.C., p. 178-230.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Map I-2095, scale 1:50,000.

McCalpin, J.P., 1983, Landslide Inventory Mapping of a 110,000-acre area of the Bridger-Teton National Forest, northeast of Jackson, Wyoming; unpublished consulting report submitted to the USDA Forest Service, Sept. 26, 1983; includes 1:24,000-scale maps of landslides in 12 7.5' quadrangles.

McCalpin, J.P., 1984, Preliminary age classification of landslides for inventory mapping: Proceedings of the 21st Annual Engineering Geology and Soils Engineering Symposium, Moscow, Idaho, April 5-6, 1984, p. 99-111.

McCalpin, J.P., 1985, Landslide Inventory Mapping of a 160,000-acre area of the Bridger-Teton National Forest, in the Salt River Range near Afton, Wyoming; unpublished consulting report submitted to the USDA Forest Service, Dec. 31,1985; includes 1:24,000-scale maps of landslides in 16 7.5' quadrangles.

Nelson, C.V., 2003, Letter report on landslides in part of the Suncrest Development, Draper, Utah: unpublished consulting report submitted to Suncrest Development, LLC, by Western GeoLogic, Salt Lake City, UT,

Nelson, C.V. and Bryant, B.A. (compilers), 2002, Surface Rupture, Liquefaction Potential, Special Study Areas, Salt Lake County, Utah: Salt Lake County Planning and Development Services Division, Department of Public Works, Salt Lake City, UT, March 2002 revision.

Soeters, R. and van Westen, C.J., 1996, Slope instability, recognition, analysis, and zonation, in Turner, A.K. and Schuster, R.L. (eds.), Landslides-- investigation and mitigation: Transportation Research Board, Special Report 247, National Academy Press, Washington, DC, p. 129-177.

Turner, A.K. and Schuster, R.L. (eds.), 1996, Landslides-- investigation and mitigation: Transportation Research Board, Special Report 247, National Academy Press, Washington, D.C., 673 p.

APPENDIX 1; Digitization of Plate 1

The hard copy, hand-colored Landslide Inventory Map at 24”x36” size was scanned at 250 dpi by the San Luis Valley GIS/GPS Authority (Alamosa, Colorado) in grayscale and saved as TIFF and JPEG files. The JPEG version was imported into MapInfo Professional v. 7.0 at GEO-HAZ and georegistered using 4 control points (Table 1) near (but not at) the map corners. These points were intersections of section lines, hill summits, or other easily-located features. The Latitude/Longitude of the control points was obtained from locating the points on the iGage “All Topo Maps: Utah” CD-ROM (iGage mapping Corporation, P.O. Box 58596, Salt Lake City, UT 84158-9912). After import and georegistration, MapInfo reported the following RMS errors for the control points; NE corner, 5 pixels; NW corner, 7 pixels; SW corner, 9 pixels; SE corner, 7 pixels. Because each pixel on a 250 dpi scan of a 1”=1000 ft map is 4 feet wide, the RMS errors cited above correspond to 20 feet to 36 feet on the ground. These errors probably result from distortions when the paper map was fed into the scanner; paper is not a stable medium and will stretch and shrink. The scanned map was saved in the UTM map projection, Zone 13, meters, using the NAD27 datum.

Table 1. Control points used to georegister the scanned map of Landslide Inventory in MapInfo Professional v. 7.0.

Location	Latitude	Longitude	RMS Error (pixels)	RMS Error (feet)
Near NE corner	40° 29.78649’	-111° 47.53955’	5	20
Near NW corner	40° 29.18049’	-111° 52.42536’	7	28
Near SW corner	40° 27.76402’	-111° 51.13869’	9	36
Near SE corner	40° 27.69861’	-111° 47.20024’	7	28

Next, we traced the polygon boundaries and lines from the scan in heads-up digitizing mode to create vector polygons and lines. We made separate files for each age and type of landslide feature:

YOUNG_scarps
YOUNG_landslides
MATURE_scarps
MATURE_landslides
OLD_scarps
OLD_landslides
RELICT_scarps
RELICT_landslides
Bedrock_contacts
Labels

Finally, we reprojected all the files into State Plane Coordinates, 1983, feet, using the NAD83 datum.

APPENDIX 2
STATISTICS OF LANDSLIDE DEPOSIT POLYGONS ON THE LANDSLIDE INVENTORY MAP

Landslide Inventory, Suncrest Development
Statistics

Polygon No.	Age	Material	Type	Acreage
1	y	d	f	2.157
2	y	d	f	1.479
3	y	d	f	0.819
4	y	d	f	3.738
5	y	d	f	1.387
6	mo	r	s	40.25
7	o	r	s	27.35
8	m	r	s	47.52
9	y	r	s	5.176
10	o	r	f	36.81
11	m	e	f	56.79
12	m	r	s	78.85
13	o	r	s	10.5
14	o	r	s	5.636
15	m	e	s	23.52
16	m	r	s	49.56
17	o	r	s	6.786
18	r	r	s	418.3
19	o	r	s	36.25
20	m	r	s	12.53
21	m	r	s	42.46
22	m	r	s	18.14
23	o	e	f	20.25
24	r	r	s	85.48
25	y	d	f	7.041
26	y	d	s	1.303
27	y	d	s	0.968
27A	y	d	s	0.4248
28	y	d	s	3.344
29	m	r	s	32.23
30	y	d	s	14.7
31	m	r	s	4.045
32	y	d	s	0.6116
33	y	d	f	1.227
34	y	d	s	0.3874
35	y	d	f	0.4103
36	y	d	s	0.7326
37	y	d	f	0.5287
38	y	d	s	0.6704

39	y	d	f	0.4453
40	o	r	s	13.49
41	m	r	s	21.72
42	o	r	s	3.916
43	m	d	s	2.259
44	m	r	s	15.39
45	m	r	s	15.2
46	o	r	s	22.97
47	m	r	s	60.07
47A	y	r	s	?
48	o	r	s	5.471
49	y	d	f	1.578
50	y	d	s	0.8193
51	o	r	s	15.12
52	m	r	s	6.689
53	o	r	s	6.524
			TOTAL	1295.023