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PRELIMINARY ANALYSIS OF LANDSLIDES TRIGGERED BY THE JANUARY 17, 1994, NORTHRIDGE EARTHQUAKE IN THE SANTA SUSANA QUADRANGLE, CALIFORNIA

By **Mario Parise**[1] *and* **Randall W. Jibson**[2]

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[1]National Research Council, CERIST, Bari, Italy
[2]U.S. Geological Survey, Golden, Colorado

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INTRODUCTION

The January 17, 1994, Northridge, California, earthquake (**M**-6.7) caused widespread damage and huge economic losses. One of the most significant geologic effects of the earthquake was the triggering of thousands of landslides over a broad area. Some of these landslides damaged and destroyed homes and other structures, blocked roads, disrupted pipelines, and caused other serious damage. Analysis of the distribution and characteristics of these landslides is important in understanding what areas may be susceptible to landsliding in future earthquakes.

In this paper, we analyze the frequency, distribution, and geometries of triggered landslides in the Santa Susana 7.5' quadrangle, an area of intense seismic landslide activity near the earthquake epicenter. To provide context, we briefly describe the Northridge earthquake and its setting, give an overview of landslides triggered by the earthquake, and describe the geology and physiography of the Santa Susana quadrangle. We then present some simple statistical measures of landslide morphology and compare them for landslides in various geologic units. Finally, we analyze landslide distribution and frequency by geologic unit and quantify measures of relative susceptibility to seismic landsliding for each unit.

THE NORTHRIDGE EARTHQUAKE AND ITS SETTING

The **M**-6.7 Northridge earthquake struck the San Fernando Valley, about 30 km northwest of Los Angeles (fig. 1), on January 17, 1994, at 4:31 a.m. Pacific standard time. Though of moderate magnitude, this was the most costly earthquake in U.S. history, with losses estimated at more than $20 billion. The earthquake occurred on a blind thrust fault (strike N.70°-80°W., dip 35°-40°S.) at a depth of about 19 km; the rupture began at the southeastern corner of the slip area and propagated upward and northwestward (Wald and others, 1994; 1996).

The San Fernando Valley and the adjacent mountains, which are part of the Transverse Ranges physiographic province, are in one of the most seismically active parts of the United States. Since 1970, three damaging earthquakes have occurred in this area: the 1971 San Fernando (**M**-6.6), the 1987 Whittier Narrows (**M**-5.9), and the 1994 Northridge (**M**-6.7) earthquakes. Although similar in magnitude to the 1994 Northridge earthquake, the 1971 San Fernando earthquake caused much less damage because it struck the sparsely populated San Gabriel Mountains, whereas the Northridge earthquake originated directly beneath the heavily populated San Fernando Valley (Hauksson and Jones, 1994); moreover, extensive growth and development since 1971 increased the risk exposure in the area.

The Northridge earthquake produced one of the richest data sets in history. About 200 digital strong-motion recordings of the mainshock were acquired, and comprehensive documentations of geologic effects, including landslides, have been completed and published (for example, papers in two special issues of Earthquakes & Volcanoes (U.S. Geological Survey, 1994) and in a special issue of the Bulletin of the Seismological Society of America (Teng and Aki, 1996).

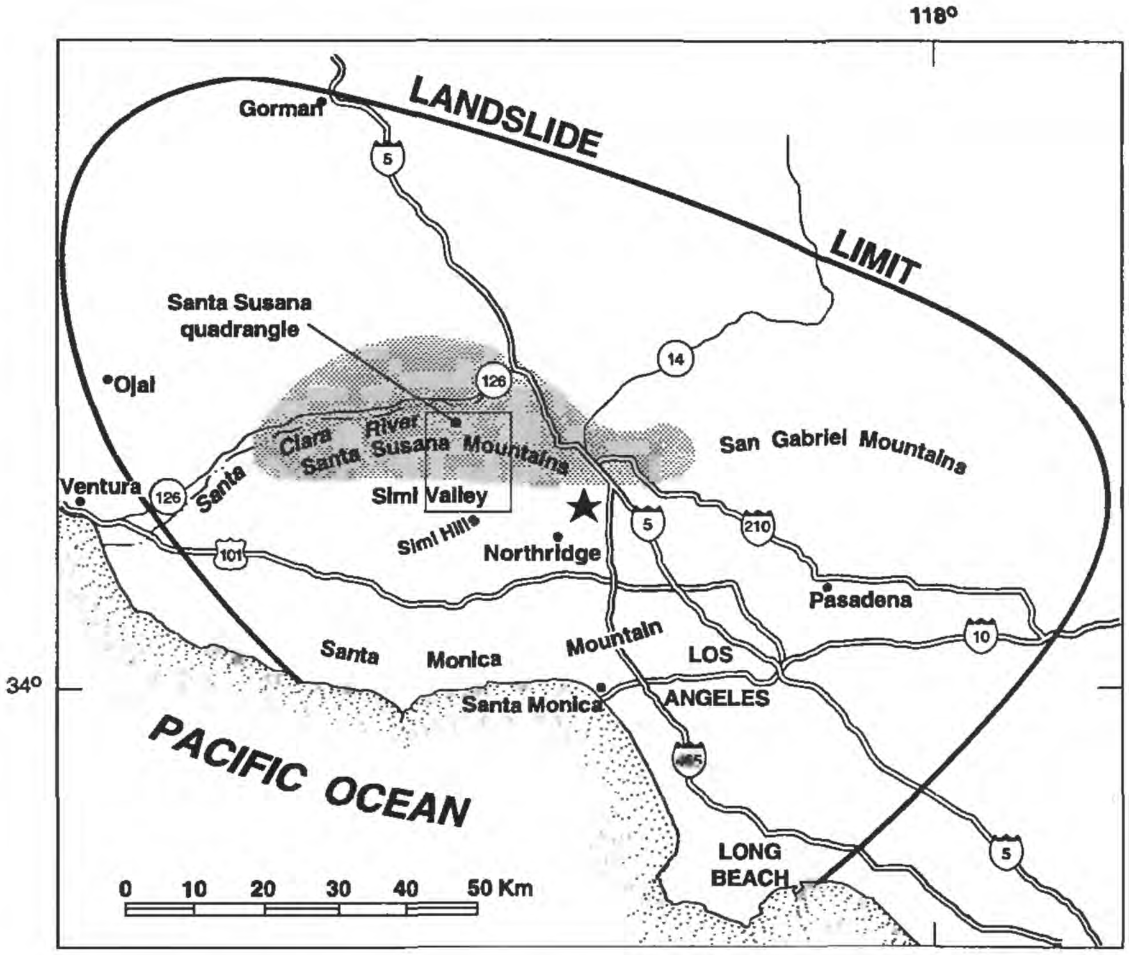

Figure 1. Map showing epicenter of Northridge earthquake (star), limit of landslides triggered by the earthquake (solid line), area of greatest landslide concentration (shaded), and location of the Santa Susana quadrangle (box).

OVERVIEW OF LANDSLIDES TRIGGERED BY THE EARTHQUAKE

In the area of greatest concentration, landslides occurred in young (late Miocene through Pleistocene), uncemented or very weakly cemented sediment that has been repeatedly folded, faulted, and uplifted in the past 1.5 m.y., signifying a very rapid deformation rate. The combination of low strength and rapid uplift creates steep, unstable slopes that are highly susceptible to failure during earthquakes (Jibson and others, 1994). Some local drainages within the Santa Susana Mountains had more than 75 percent of their slope areas denuded by landsliding triggered by strong shaking during the earthquake (Jibson and others, 1994).

By far the most common types of landslides triggered by the earthquake, numbering in the thousands, were highly disrupted, shallow falls and slides of rock and debris. Far less numerous (tens to perhaps hundreds) were deeper, more coherent slumps and block slides; these slides occurred primarily in somewhat more cohesive or competent materials (Harp and Jibson, 1995).

The Northridge earthquake triggered one liquefaction-induced landslide in the Santa Susana quadrangle. The slide occurred in artificial fill in a quarry in Tapo Canyon, north of Simi Valley. Strong shaking caused liquefaction of an embankment tailings dam, and a flow slide of tailings through a breach in the dam resulted (Stewart and others, 1995). The overall failure affected an area greater than 75,000 m^2. The liquefaction failure at Tapo Canyon will not be considered in the morphometric and statistical analysis.

Harp and Jibson (1995; 1996) mapped landslides triggered by the Northridge earthquake from airphotos taken about 6 hours after the earthquake by the U.S. Air Force (nominal scale 1:60,000). Landslide perimeters were then digitized in the Arc/Info Geographic Information System (GIS) for plotting and analysis.

THE SANTA SUSANA QUADRANGLE

We selected the Santa Susana quadrangle for analysis of triggered landslides. The Santa Susana quadrangle is in the area of greatest landslide concentration (fig. 1) and includes a large portion of the Santa Susana Mountains. Major drainages are aligned north-south to north-northeast-south-southwest for most of their courses. Elevations in the quadrangle range from about 270 m in the Simi Valley up to about 950 m in the Santa Susana Mountains.

The physiography of the area resembles that of the rest of the Transverse Ranges: parallel, east-west trending mountain ranges and intervening, sediment-filled valleys. The most prominent feature in the Santa Susana quadrangle is the E-W and ESE-WNW orientation of its elongate mountains and valley. The young, weakly cemented to uncemented sedimentary rocks erode readily and have formed deeply incised valleys separated by steep-sided ridges culminating in sharp divides.

The major areas having steep slopes include the Santa Susana Mountains in the northern and northeastern parts of the quadrangle, Oak Ridge and Big Mountain in the northwestern corner, and the foothills of the Simi Hills in the southern and southeastern parts of the quadrangle. The broad, nearly flat Simi Valley lies between the Santa Susana Mountains and Simi Hills.

Table 1 lists the geologic units cropping out in the Santa Susana quadrangle (geology from Yerkes and Campbell 1995, 1997), their lithologies, and their exposure areas; the proportion of the quadrangle covered by each geologic unit also is indicated. Holocene alluvium (Qal), which in general is exposed in relatively flat-lying areas not susceptible to landslides, covers 22 percent of the study area. Among the geologic units in sloping areas, the Chatsworth and Modelo Formations have the greatest exposure: each covers about 13 percent of the quadrangle. Each of the other formations covers less than 10 percent of the study area.

Three geologically distinct areas can be identified in the Santa Susana quadrangle: (1) the prominent mountain ridges (Santa Susana Mountains, Oak Ridge, Big Mountain) in the northern half of the quadrangle, which consist primarily of Neogene and Pleistocene sediments; (2) the Simi Valley, consisting primarily of Quaternary alluvium, in the south-central and southwestern parts of the quadrangle; and (3) the Simi Hills, consisting of Upper Cretaceous and lower Tertiary rocks, in the southern and southeastern part of the quadrangle.

The Santa Susana Mountains are composed of uncemented or weakly cemented sandstone, siltstone, and shale. As noted previously, these mountains are being uplifted rapidly and form very steep slopes. Ridges extend primarily in northwest-southeast-trending bands that parallel the axes of the main faults and folds in the area. Strata generally dip northeastward or southwestward. Principal formations include (1) the Miocene Modelo Formation, consisting primarily of shale with some sandy subunits; (2) the Pliocene Towsley and Pico Formations, consisting of sandstone and siltstone; and (3) the Pleistocene Saugus Formation, consisting of sandstone with some conglomerate and siltstone. The area between Big Mountain and Simi Valley, in the west-central part of the quadrangle, consists of the Oligocene and Eocene Sespe Formation, made up of sandstone, conglomerate, and claystone. The Simi Hills, bounding the Simi Valley on the south and west, are composed of the oldest and strongest formations in the quadrangle. Principal formations include (1) the Upper Cretaceous Chatsworth Formation, a well-cemented sandstone; (2) the locally well-cemented Simi Conglomerate of Paleocene age;(3) the Paleocene-Eocene Santa Susana Formation, consisting of mudstone with local sandstone interbeds; and (4) the Eocene Llajas Formation, consisting of sandstone, siltstone and conglomerate.

FREQUENCY, DISTRIBUTION, AND MORPHOLOGIES OF TRIGGERED LANDSLIDES IN THE SANTA SUSANA QUADRANGLE

Numbers and types of landslides

A total of 1,563 seismically triggered landslides were mapped in the Santa Susana quadrangle. These landslides cover an area of about 3.4 km^2, which is 2.13 percent of the entire quadrangle. The landslides are primarily concentrated along two bands. The largest concentration extends northwest-southeast through the Santa Susana Mountains. The maximum concentration of landslides in this area occurs in the northeast corner of the quadrangle in the Towsley Formation. The second band trends east-west across the central part of the Santa Susana quadrangle and includes the slopes along the northern border of the Simi Valley. Other landslides are scattered in various parts of the quadrangle, primarily in its northern half; very few slides occur along Oak Ridge or in the Simi Hills.

Table 1—Geologic units, lithologies (Yerkes and Campbell, 1995), exposure areas, and proportional exposure areas in the Santa Susana quadrangle.

Geologic unit	*Subunit*	*Age*	*Lithologic description*	*Exposure area (km^2)*	*Proportional exposure (percent)*
Alluvium	Qal	Holocene	alluvial deposits	35.1	22.0
	Qao	Holocene - Pleistocene	older alluvial deposits		
Landslide deposits	Qls	Holocene - Pleistocene	landslide deposits	11.4	7.2
	Qls?	Holocene - Pleistocene	likely landslide deposits		
Pleistocene deposits	Qsw	Holocene - Pleistocene	slope wash		
	Qt	Pleistocene	terrace deposits	5.6	3.5
	Qft	Pleistocene	fan and terrace deposits undivided		
Saugus Formation	Qs	Pleistocene	sandstone, conglomerate, siltstone	15.2	9.5
	Qsm	Pleistocene	sandstone and conglomerate		
Pico Formation	Tp	Pliocene - Pleistocene?	sandy siltstone, sandstone and pebbly sandstone		
	Tpc	Pliocene - Pleistocene?	sandstone and conglomerate	2.1	1.3
	Tps	Pliocene - Pleistocene?	siltstone		
Towsley Formation	Tw	Miocene - Pliocene	fine- to coarse-grained sandstone		
	Twc	Miocene - Pliocene	chiefly sandstone	12.6	7.9
	Tws	Miocene - Pliocene	chiefly siltstone or mudstone		
Modelo Formation	Tm	Miocene	shale, silty to sandy, cherty, siliceous, diatomaceous, or clayey, interbedded sandstone		
	Tm2	Miocene	siliceous shale and bedded chert		
	Tm3	Miocene	diatomaceous to siliceous shale and chert	20.8	13.0
	Tm4	Miocene	siltstone with limestone concretions		
	Tmd	Miocene	diatomaceous shale		
	Tms	Miocene	siliceous shale, siltstone		
Topanga Group	Tt	Miocene	sandstone	0.2	0.1
Sespe Formation	Ts	Eocene - Oligocene	sandstone, conglomerate, claystone	11.3	7.1
Llajas Formation	Tl	Eocene	conglomerate, sandstone, siltstone	8.8	5.6
	Tlc	Eocene	pebble conglomerate and interbedded thin sandstone		
Santa Susana Formation	Tss	Paleocene - Eocene	mudrock, with subordinate sandstone and conglomerate	10.4	6.5
Simi Conglomerate	Tsc	Paleocene	conglomerate, interbedded sandstone, minor mudrock	5.2	3.2
Chatsworth Formation	Kc	Late Cretaceous	sandstone, with siltstone interbeds	20.6	12.9

In order to perform morphometric and statistical analyses on the landslides triggered by the earthquake, the landslides in the Santa Susana quadrangle were divided into two samples: single landslides and landslide complexes (fig. 2). Landslide complexes are defined as areas where seismic shaking triggered multiple coalescing failures of surficial material, and it was not possible to outline the boundaries of each individual landslide.

A total of 1,502 single landslides covered 2.36 km^2. By contrast only 60 landslide complexes occurred, but they covered 1.04 km^2 (table 2, fig. 2). Thus, landslide complexes are far fewer in number than single landslides, but they occupy, on average, much larger areas.

Landslide morphologies

Simple orphometric parameters (including area, length, width, aspect ratio, and slope angle (were computed for both single landslides and landslide complexes (table 2). Single-landslide areas ranged from 23 m^2 to more than 25,000 m^2 and averaged 1,520 m^2. Landslide complexes averaged more than 10 times larger, at more than 17,000 m^2, and ranged in area from almost 2,500 m^2 to more than 100,000 m^2.

Landslide length—the minimum distance from the tip of a landslide to its crown (terminology after IAEG Commission on Landslides, 1990)—was measured along the direction of landslide movement. Width was measured perpendicular to length in the area of maximum landslide breadth. Lengths of single slides ranged from 9 to more than 350 m and averaged about 70 m. Lengths of landslide complexes averaged more than twice as great at 186 m. Single-landslide widths ranged from 4 to almost 200 m and averaged 26 m. Landslide complexes, which commonly extended along entire ridge lengths, had average widths of more than 150 m and were as wide as 543 m.

The shape of a landslide can be described by its aspect (length/width) ratio. Comparable values of length and width, yielding aspect ratios close to 1, are generally typical of rotational slides, and, to a lesser extent, translational slides and soil slips. When the length is much longer than the width, the ratio assumes greater values, indicating elongated shapes typical of flow-type landslides and disrupted slides having long to very long runout distances.

Aspect ratios in table 2 clearly show the elongated shape of the great majority of single landslides, which have a mean ratio of 2.6. This elongation resulted, in general, from moderately long runout distances down steep slopes below landslide source areas. Landslide complexes, on the other hand, have mean ratios of 1.2, indicating very little elongation. Although their runout distances averaged longer than those for single landslides, most of the complex landslides extended for large distances along ridge lines, which yielded aspect ratios near 1.

Slope was computed in landslide source areas (table 2). For single and complex landslides, mean slopes in landslide source areas were 36° and 38°, respectively.

Landslide distribution by geologic unit

Figure 3 and table 3 show landslide occurrence by geologic unit. The greatest areal

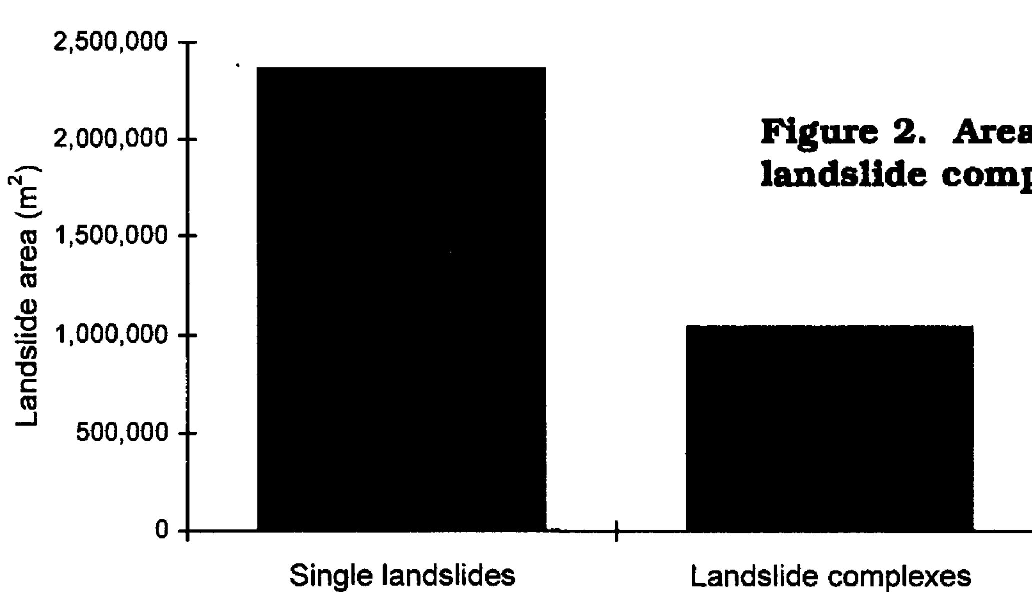

Figure 2. Areas of single landslides and landslide complexes.

Table 2—Frequency and morphometric parameters of landslides.

		Single landslides	Landslide complexes
Frequency		1,502	60
Area (m^2)	*total*	2,359,095	1,039,476
	minimum	23	2,471
	maximum	25,257	106,765
	mean	1,520	17,324
	standard deviation	2,061	19,121
Length (m)	*minimum*	9	50
	maximum	367	435
	mean	69	186
	standard deviation	47	87
Width (m)	*minimum*	4	49
	maximum	195	543
	mean	26	154
	standard deviation	21	115
Mean aspect ratio		2.6	1.2
Mean slope (°)		36	38

extent of landslides (more than 1 km^2) was in the Towsley Formation. The Modelo, Sespe, Llajas, and Pico Formations, respectively, had the next highest values of area affected by landslides. The unnamed Pleistocene deposits, Topanga Group, and Chatsworth Formation are the only geologic units whose landslide area does not exceed 10,000 m^2.

Some formations are divided into subunits, and considerable variability in landslide occurrence exists between subunits. The sandstone of the Towsley Formation (Twc) is by far the most affected by landsliding, with a total landslide area greater than 450,000 m^2. Siltstone of the Modelo Formation (Tm4), siltstone and mudstone of the Towsley Formation (Tws), siltstone of the Pico Formation (Tps), sandstone and conglomerate of the Saugus Formation (Qsm) all have landslide areas greater than 100,000 m^2 (table 3).

Table 3 also lists spatial frequency of landslides in the geologic units. Total number of landslides from this table is much greater than the 1,502 single landslides and 60 landslide complexes reported in table 2 because those landslides involving more than one geologic unit were counted in both affected units. The Towsley Formation, with more than 600 landslides, has the highest number of landslides. The Modelo (377), Sespe (242), Llajas (212), Saugus (171), and Pico (140) Formations also have relatively high landslide occurrences.

Table 4 compares areas of single landslides and landslide complexes for each geologic unit. The Modelo, Towsley, and Sespe Formations had the largest areas of landslide complexes. Despite the small number of landslide complexes involved, the Pico, Modelo, and Sespe Formations had more area covered by landslide complexes than single landslides.

LANDSLIDE SUSCEPTIBILITY OF GEOLOGIC UNITS

Landslide susceptibility index

The total area affected by landslides in a particular geologic unit depends, in part, on the aerial exposure of that unit within the study area. A measure of the susceptibility of each unit to seismic slope failure can be developed by simply dividing the landslide area within each unit by the total outcrop area of that unit. This yields the percentage of the outcrop area that failed, which we term the

Table 3—Landslide areas, frequencies, susceptibility indices, and frequency indices for geologic units and subunits.

Geologic unit/ subunit	*Exposure area (m^2)*	*Landslide area (m^2)*	*Number of landslides*	*Susceptibility index (percent)*	*Frequency index (ls/km^2)*
Alluvium	35,145,201	9,276	31	0.03	0.9
Qal	33,888,954	9,276	31	0.02	0.9
Qao	1,256,247	0	0	0	0
Landslide deposits	11,411,956	109,217	81	0.96	7.1
Qls	10,975,849	107,217	74	0.98	6.7
Qls?	436,107	1,999	7	0.46	16.1
Pleistocene deposits	5,654,808	8,129	14	0.14	2.5
Qsw	37,231	0	0	0	0
Qft	2,268,970	5,076	8	0.22	3.5
Qt	3,385,838	3,054	6	0.09	1.8
Saugus Formation	15,235,368	174,139	171	1.14	11.2
Qs	7,984,219	71,767	84	0.90	10.5
Qsm	7,213,918	102,372	87	1.42	12.1
Pico Formation	2,063,646	250,915	140	12.16	67.8
Tp	1,378,534	126,435	82	9.17	59.5
Tpc	30,077	6,243	5	20.75	166.2
Tps	655,034	118,238	53	18.05	80.9
Towsley Formation	12,652,283	1,138,306	605	9.00	47.8
Tw	3,658,708	537,990	258	14.70	70.5
Twc	6,809,802	451,839	255	6.63	37.5
Tws	2,183,773	148,478	92	6.80	42.1
Modelo Formation	20,796,341	680,306	377	3.27	18.1
Tm	11,423,893	458,660	275	4.01	24.1
Tm2	122,978	0	0	0	0
Tm3	1,692,576	1,328	2	0.08	1.2
Tm4	6,824,070	187,023	70	2.74	10.3
Tmd	460,788	22,165	15	4.81	32.6
Tms	272,036	11,130	15	4.09	55.1
Topanga Group	220,032	5,167	17	2.35	77.3
Sespe Formation	11,285,099	477,710	242	4.23	21.4
Llajas Formation	8,854,527	359,529	212	4.06	23.9
Tl	8,737,702	334,682	197	3.83	22.6
Tlc	116,826	24,847	15	21.27	128.4
Santa Susana Fm.	10,440,678	58,132	57	0.56	5.5
Simi Conglomerate	5,193,767	49,194	66	0.95	12.7
Chatsworth Fm.	20,579,422	2,922	6	0.01	0.3

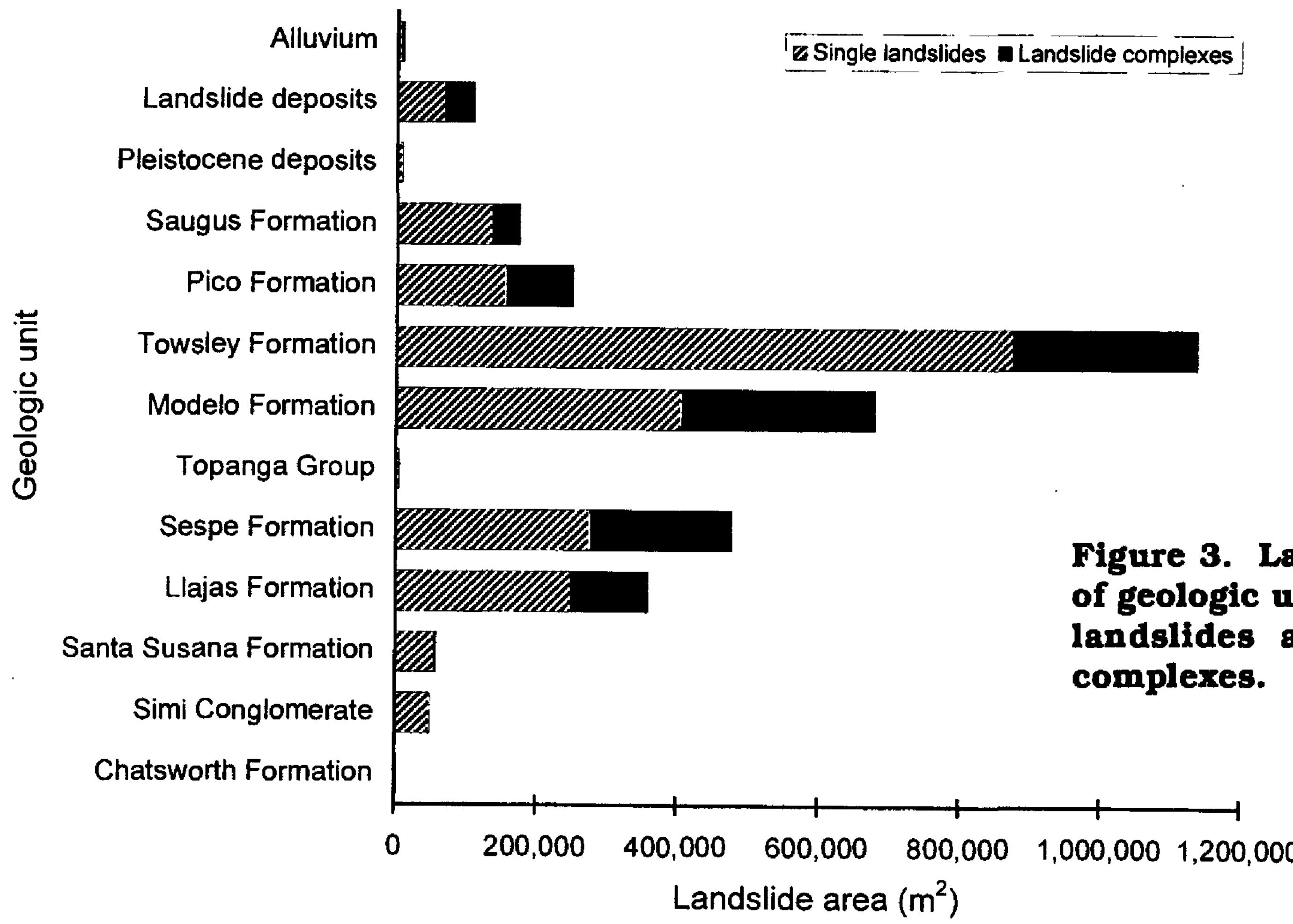

Figure 3. Landslide areas of geologic units for single landslides and landslide complexes.

susceptibility index. Table 3 and figure 4 show the susceptibility indices of geologic units.

The Pico (12.16 percent) and Towsley (9.00 percent) Formations have by far the highest susceptibility indices. The Sespe (4.23 percent), Llajas (4.06 percent) Modelo (3.27 percent), and Topanga (2.35 percent) Formations also have susceptibility indices greater than the average value (2.13 percent) for the entire quadrangle.

In regard to geologic subunits, note the very high values of susceptibility index for the conglomerate and interbedded sandstone of the Llajas Formation (Tlc = 21.27 percent), as well as for the two subunits of the Pico Formation: sandstone and conglomerate (Tpc = 20.75 percent), and siltstone (Tps = 18.05 percent). The very small outcrop area of the Tlc subunit of the Llajas Formation makes drawing any conclusion about its susceptibility uncertain, but the subunits of the Pico do appear to have very high susceptibilities.

Landslide frequency index

A measure of the spatial frequency of landsliding within a geologic unit can be determined by simply dividing the number of landslides within a unit by the exposure area of that unit, which indicates the number of landslides per square kilometer (ls/km^2). A very broad range of landslide frequencies is apparent (table 3 and fig. 5). The Topanga, Pico, and Towsley Formations have the highest frequency indices, at 77, 68, and 48 ls/km^2, respectively. The Simi Conglomerate and Llajas, Sespe, Modelo, and Saugus Formations, ranging from 11 to 24 ls/km^2, have moderately high frequencies. The lowest frequency index is in the more well cemented rock of the Chatsworth Formation (0.3 ls/km^2).

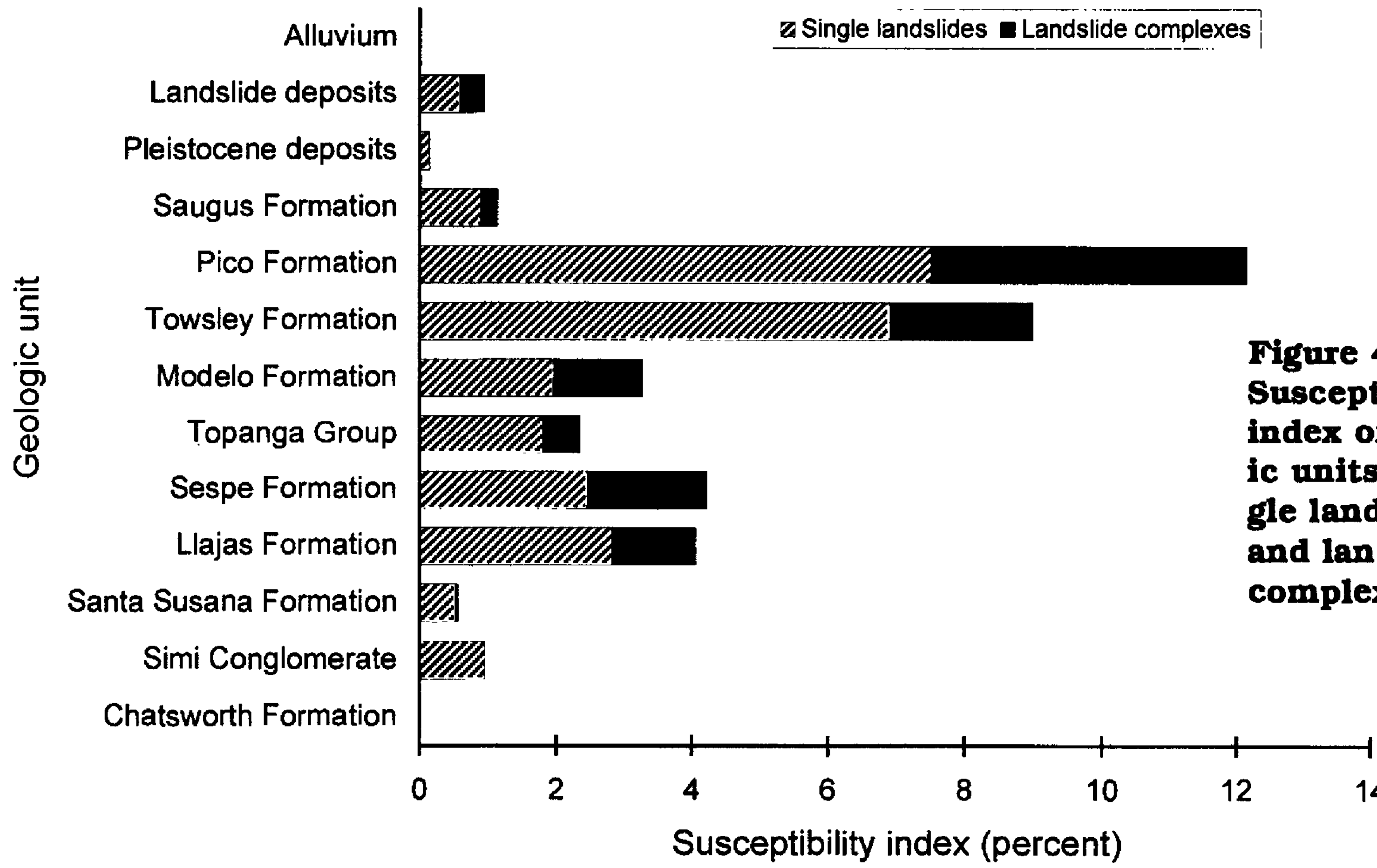

Figure 4. Susceptibility index of geologic units for single landslides and landslide complexes.

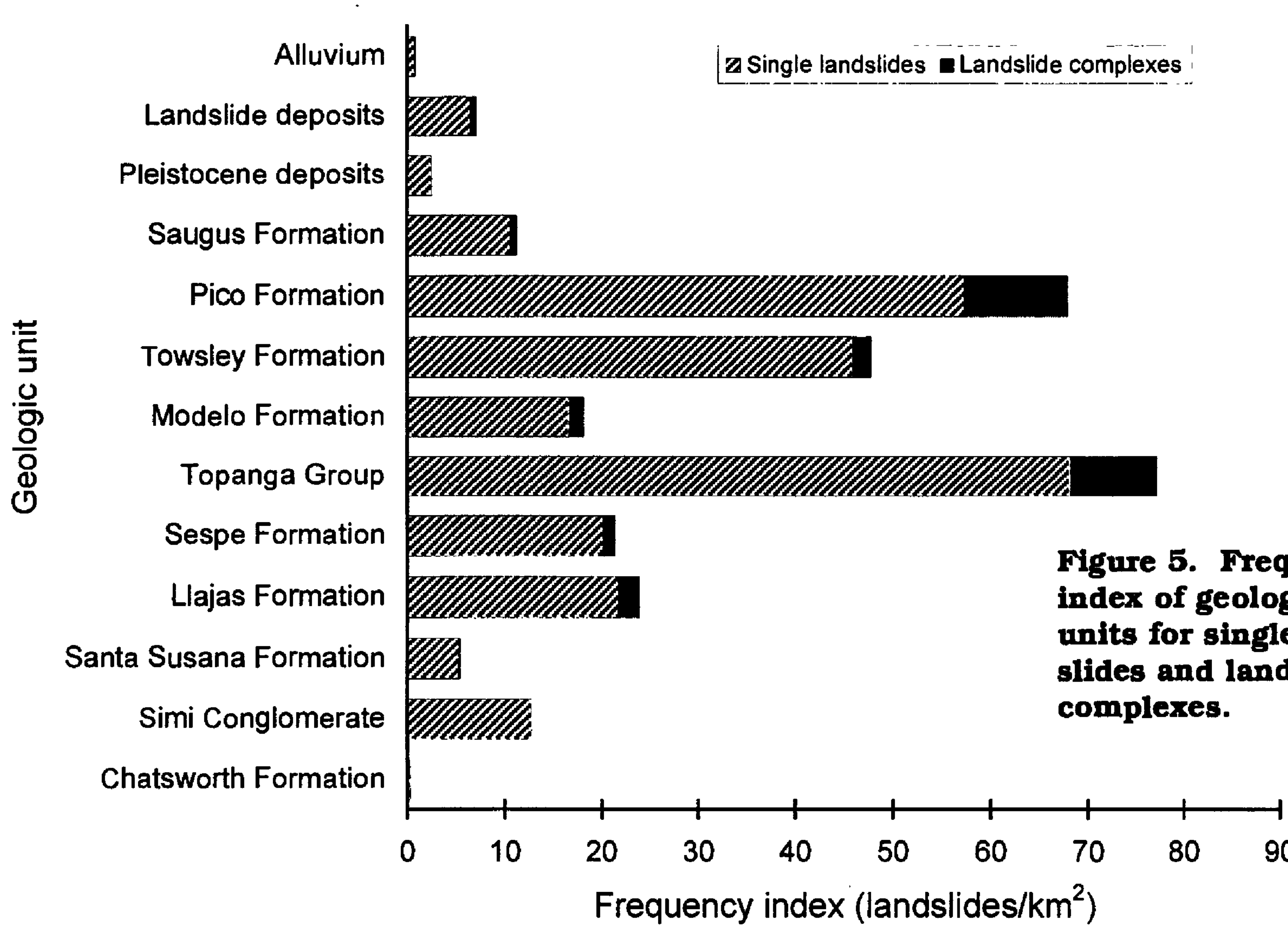

Figure 5. Frequency index of geologic units for single landslides and landslide complexes.

Table 4—Areas of single landslides and landslide complexes by geologic unit.

Geologic unit	*Area of single landslides (m^2)*	*Area of landslide complexes (m^2)*	*Total landslide area (m^2)*
Alluvium	5,322	3,954	9,276
Landslide deposits	66,609	42,608	109,217
Pleistocene deposits	8,130	0	8,130
Saugus Formation	133,905	40,234	174,139
Pico Formation	154,976	95,940	250,915
Towsley Formation	874,212	264,094	1,138,306
Modelo Formation	404,984	275,322	680,306
Topanga Group	3,964	1,203	5,167
Sespe Formation	275,931	201,779	477,710
Llajas Formation	249,037	110,493	359,529
Santa Susana Formation	54,284	3,848	58,132
Simi Conglomerate	49,194	0	49,194
Chatsworth Formation	2,922	0	2,922

Table 5—Seismic landslide susceptibility rankings of geologic units in the Santa Susana quadrangle. Geologic units listed in decreasing order of susceptibility.

Geologic unit	*Susceptibility index (percent)*	*Frequency index (ls/km²)*	*Seismic landslide susceptibility*
Pico Formation	12.16	67.8	Very High Susceptibility
Towsley Formation	9.00	47.8	
Topanga Group	2.35	77.3	
Llajas Formation	4.06	23.9	High Susceptibility
Sespe Formation	4.23	21.4	
Modelo Formation	3.27	18.1	
Saugus Formation	1.14	11.2	
Simi Conglomerate	0.95	12.7	
Landslide deposits	0.96	7.1	Moderate Susceptibility
Santa Susana Formation	0.56	5.5	
Alluvium	0.03	0.9	Low Susceptibility
Pleistocene deposits	0.14	2.5	
Chatsworth Formation	0.01	0.3	

Evaluation of landslide susceptibility of geologic units

The two indices defined above provide an objective measure of relative seismic landslide susceptibility of geologic units. The susceptibility index measures the proportion of outcrop area that experienced landsliding, and the frequency index measures the spatial density of landslides, regardless of size. Inspection of table 3 indicates that, in most cases, the susceptibility rankings using the two methods yield similar results. One exception is the Topanga Group, which had the highest frequency index but a more moderate susceptibility index. This means that outcrops of the Topanga Group experienced large numbers of relatively small landslides. Similarly, the Simi Conglomerate had the lowest frequency index but a moderate susceptibility index, indicating a small number of larger landslides.

Taking both indices into account, we propose the susceptibility ranking shown in table 5 to evaluate the relative seismic landslide susceptibilities of the geologic units. Criteria for classification are as follows: susceptibility index greater than 5 percent or frequency index greater than 30 ls/km^2 is very high susceptibility; susceptibility index between 1 and 5 per cent or frequency index between 10 and 30 ls/km^2 is high susceptibility; susceptibility index between 0.5 and 1 percent or frequency index between 3 and 10 ls/km^2 is moderate susceptibility; and susceptibility index less than 0.5 percent and frequency less than 3 ls/km^2 is low susceptibility.

Among the most susceptible units, the Pico and Towsley Formations are, by far, the most susceptible to seismically triggered failure. The Topanga Group did not affect a huge proportion of its outcrop area but did produce a very large number of failures. Among bedrock units, the Chatsworth Formation is, by far, the least susceptible to seismic failure. These susceptibility rankings apply only to seismic triggering conditions; various geologic units may have different relative susceptibilities to failure in nonseismic conditions.

CONCLUSIONS AND ONGOING RESEARCH

Analysis of the landslides triggered by the Northridge earthquake provides valuable insights into the characteristics of seismically triggered landslides. Our susceptibility ranking of geologic units shows clear distinctions between the relative susceptibilities of various units. The Pico and Towsley Formations have very high susceptibilities to seismically triggered failure, and several other units have high and moderate susceptibilities. Some geologic subunits showed particularly high susceptibilities; landslide incidence in these units should be examined in other quadrangles to see if this extreme susceptibility is widespread.

ACKNOWLEDGMENTS

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