DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Maps showing landslide features and related ground deformation in the Woodlawn area of the Manoa Valley, City and County of Honolulu, Hawaii

by

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INTRODUCTION

As part of a cooperative study between the U.S. Geological Survey and the City and County of Honolulu, Hawaii, we have systematically mapped landslide features in a residential area on the east side of the Manoa Valley, about one mile northeast from the Manoa campus of the University of Hawaii (fig. 1). We call the three landslides the Alani-Paty, Hulu-Woolsey, and Woolsey Place landslides, after the streets that occupy their upper parts. Two of the landslides, the Hulu-Woolsey and Woolsey Place landslides, are physically connected but are described separately here because these landslides have different movement histories and have been treated separately by the City and County of Honolulu. This report describes how and why the maps were made, discusses the uses and limitations of the maps, and then describes the landslides and the information contained in the maps.

WHY AND HOW THE MAPS WERE MADE

Visible evidence of ground distortion was portrayed on the maps so that the several disparate styles of deformation evident in different parts of the area could be seen in their proper spatial relationship. For landslides elsewhere, such portrayals of deformation typically show kinematically reasonable, coherent patterns that define the overall nature of the ground movement. Clear definition of the ground movement is generally necessary for the success of remedial measures.

The residential developments that cover the landslide area offer advantages and disadvantages to mapping landslide features. Numerous curbs, walls, slabs, foundations, and utility poles afford excellent, sensitive indicators of ground distortion, without which only the major features formed by ground movement would have been detectable. However, many of these structures have been repaired over the years, in some cases repeatedly, so that absence of damage to structures did not necessarily mean absence of landslide movement. Also, modification of the natural landscape during development eliminated evidence of pre-development ground movement, and continuing maintenance of yard areas has served to conceal most of the direct evidence of movement in the ground itself. Additionally, much of the valley, and, indeed, much of the island, is covered by bouldery, clayey soils that tend to creep gradually downslope. These soils are also difficult to compact successfully as fill. Thus, most developed areas on hillslopes exhibit some distress to structures. We had to distinguish the serious damage related to landslide movement from lesser damage related to soil creep and settlement of fill, using as evidence the unrepaired remains of structural damage.

We mapped the area during the periods January 20 to February 4, and April 18 to 27, 1989, using a planimetric base map provided by the City and County of Honolulu. Mapped damage to structures included extension (pulling apart), shortening or buckling, rotation, and shearing (fig. 2). The field map of damage to structures was drawn at a scale of 1 in. equals 25 ft, the smallest scale that allows damage to be shown in its correct position and size. Examples of field mapping are shown in figure 3.

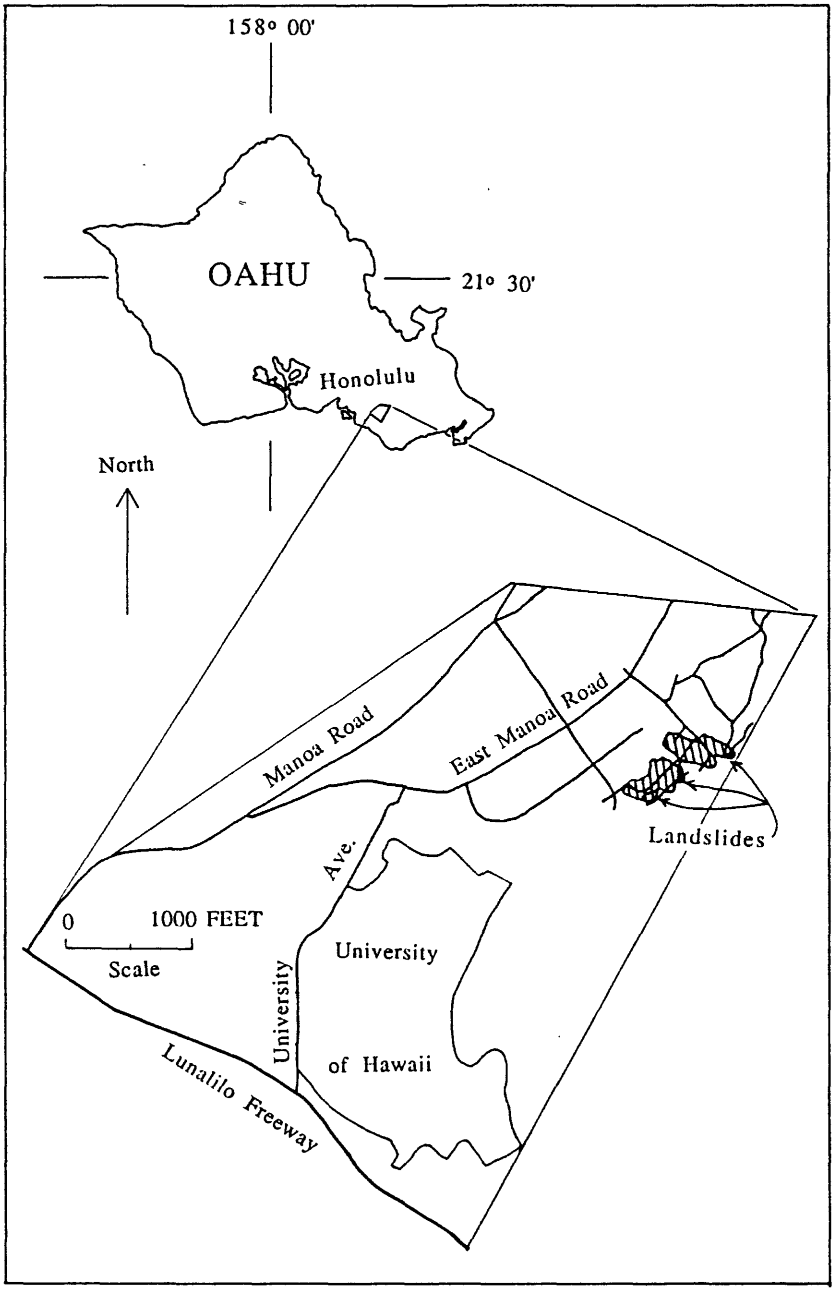
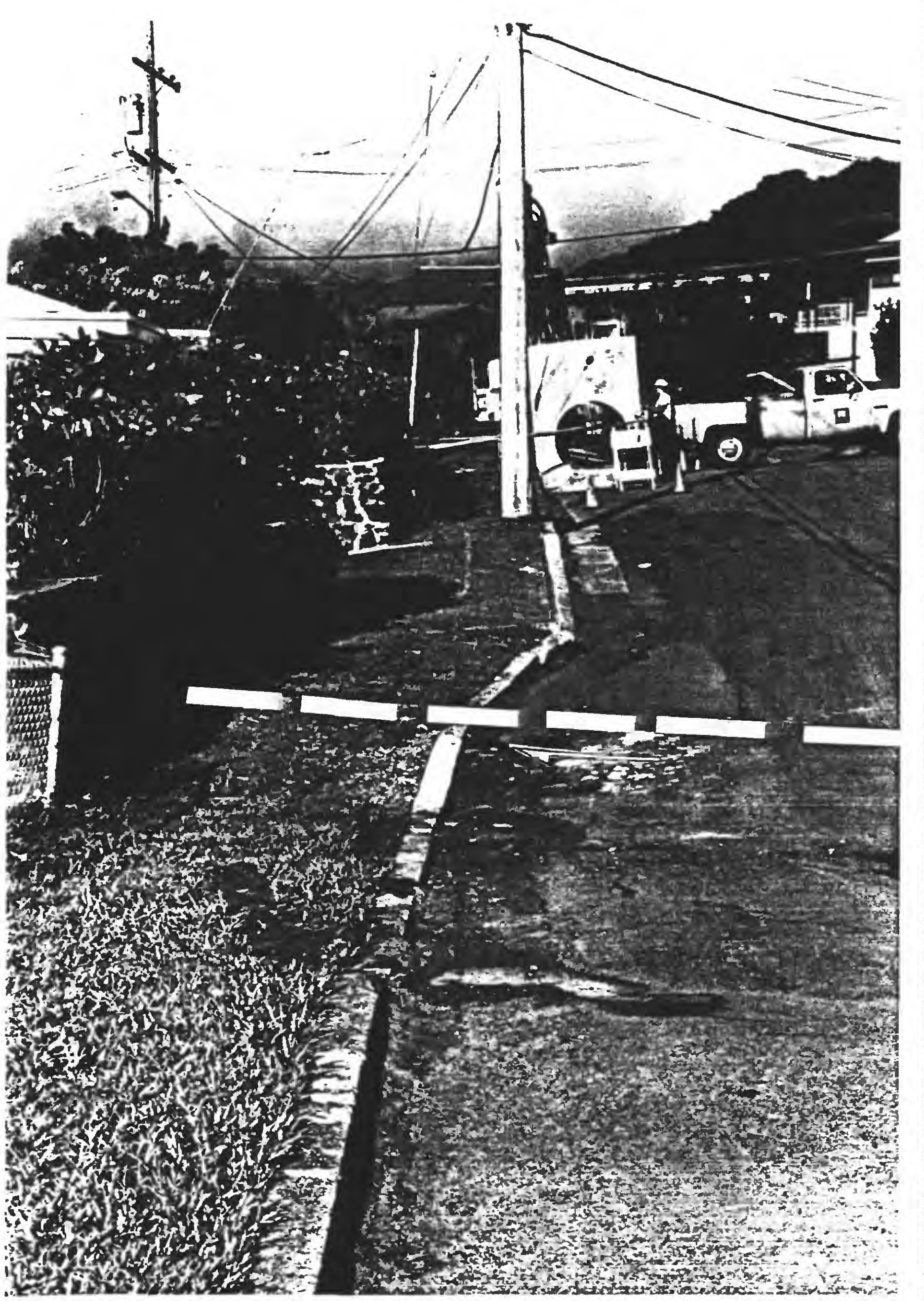
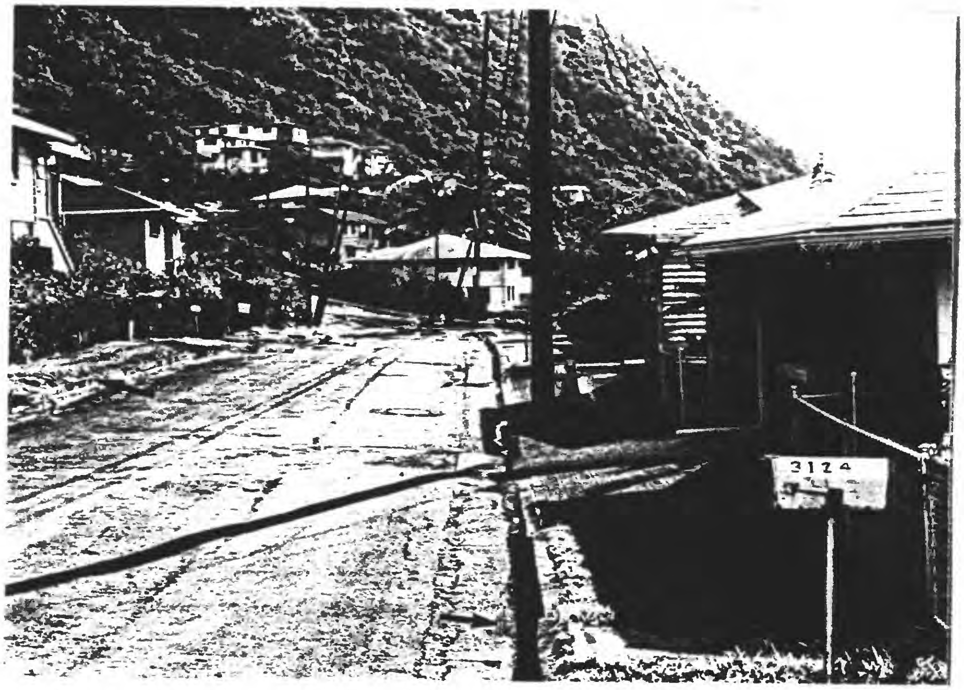


Figure 1. Map showing location of landslides in the Woodlawn area, Manoa Valley, Honolulu, Hawaii.



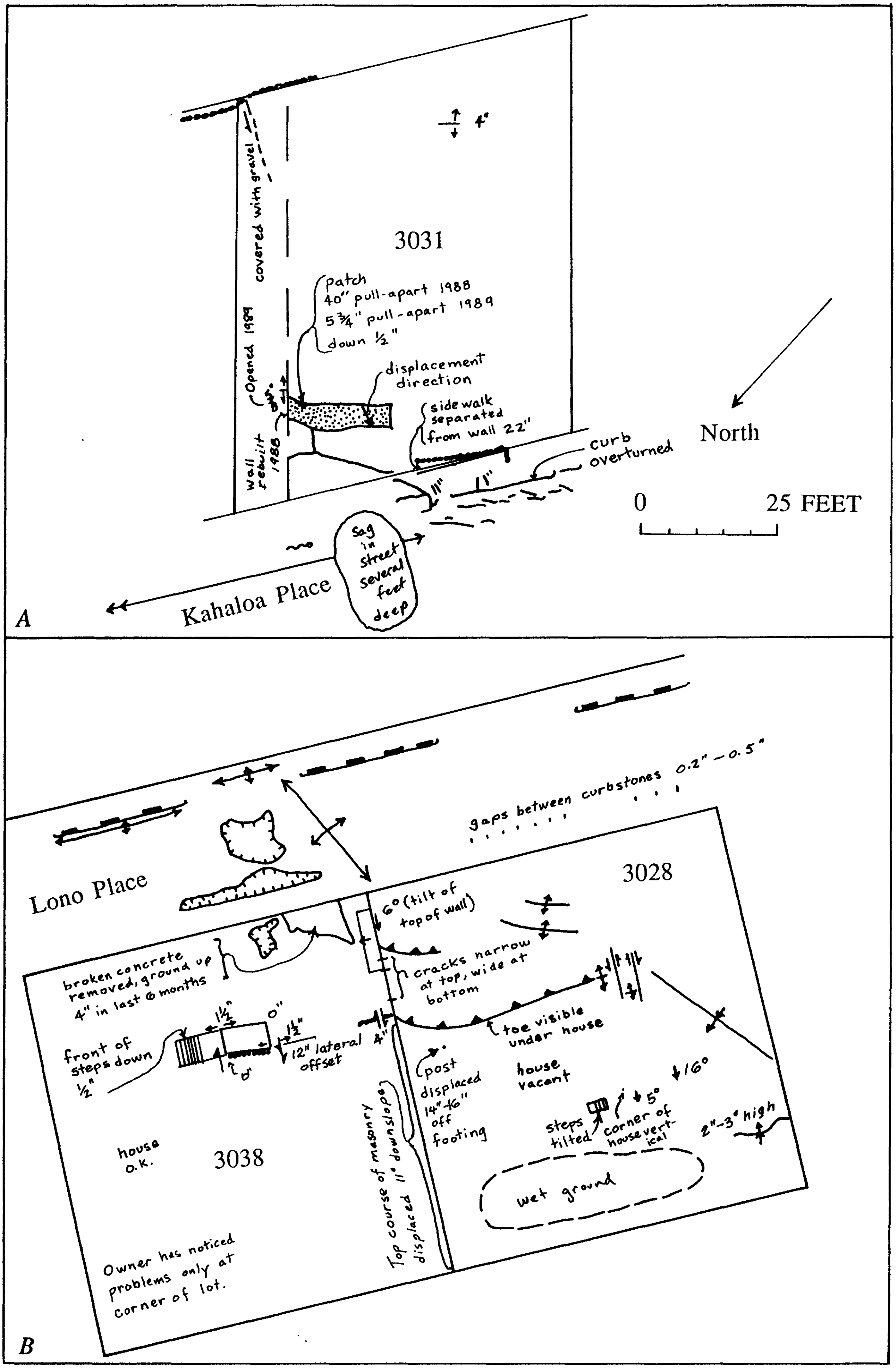
A

Figure 2. Photographs showing examples of damage on the Alani-Paty landslide. A. Offset caused by shearing is evident in the curb at 3069 Lanikaula Street. The curb line in the foreground has been displaced to the left about 3 feet relative to the curb line in the background. Note the absence of evidence for deformation in the lawn to the left. The dashed line shows the approximate location of the shear fracture that bounds the north flank of the landslide, and the arrow indicates the direction of movement.

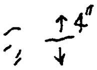


B

Figure 2. (continued) B. View toward the southwest along Lanikaula Street toward the intersection with Woolsey Place. Tilted curbstones (arrow at bottom center), bulging of lawns downslope from walls on the left (arrow at left center), and formation of bumps in the street (center) are evidence for shortening. Much damage has been repaired including replacement of some utility poles (background).


A
3031
covered with gravel
Opened 1989
Wall rebuilt 1988
patch
40" pull-apart 1988
5 3/4" pull-apart 1989
down 1/2"
displacement direction
sidewalk separated from wall 22"
curb overturned
11"
11"
Sag in street several feet deep
Kahaloa Place
4'
North
0
25 FEET
B
Lono Place
gaps between curbstones 0.2" – 0.5"
3028
6° (tilt of top of wall)
cracks narrow at top, wide at bottom
toe visible under house
broken concrete removed, ground up 4" in last 6 months
front of steps down 1/2"
1 1/2"
0"
1 1/2"
12" lateral offset
4"
post displaced 14"-16" off footing
house vacant
1/6°
5°
steps tilted
corner of house vertical
2"-3" high
wet ground
house O.K.
3038
Top course of masonry displaced 11" downslope
Owner has noticed problems only at corner of lot.

EXPLANATION


Cracks in pavement, walls, or ground surface--Arrows and number indicate separation in inches


Patch in wide crack


Landslide toe--Sawteeth on moving ground

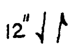

Concrete slab overriding curb--Rectangles on edge of slab

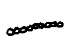

Closed depression


Linear ridge--Large arrows indicate tips of ridge


Escarpment--Arrows indicate direction of ground slope


Tilt of an originally horizontal surface--Arrow shows direction of tilt, number indicates tilt angle in degrees


Lateral offset--Arrows indicate sense of offset, number indicates offset in inches


Stone or concrete-masonry wall


Spring or seep

Figure 3. Examples of field maps. A. Part of a field map showing cracks and lateral offsets at 3031 Kahaloa Place. B. Part of field map showing evidence of shortening in Lono Place and shortening across toe at 3028 Lono Place.

During field mapping, patterns of damage were used to locate landslide boundaries and to recognize areas distorted in different styles. For example, consistent patterns of shear offset of curbs, walls, and walks were used to locate the lateral boundaries of the landslides. Similarly, consistent evidence for shortening (compression) in the lower parts of the landslides helped locate the downslope limits to movement.

Data from the field maps were summarized to produce the maps of this report, which show landslide boundaries and deformation at a scale of 1 in. equals 100 ft. Plate 1 shows the boundaries of the main bodies of the landslides, as well as locations of other landslide features both within and beyond these boundaries. Features within the landslide boundaries define smaller elements within the landslide masses. Features beyond the landslide boundaries indicate places where patterns of damage are consistent with potential enlargement of the landslides. Plate 2 shows, in addition to landslide boundaries, locations of shortening (compression), shear, and stretching (extension) on the Alani-Paty and Hulu-Woolsey landslides. Such areas in the Woolsey Place landslide could not be determined because regrading has obliterated any evidence for style of deformation.

USES OF THE MAPS

We expect the maps to be useful for three purposes. First, the map of boundaries and related features (pl. 1) is a baseline representation of the sizes, shapes, and positions of the landslides as of January, February, and April 1989. By comparing future patterns of landslide features to the patterns portrayed here, changes of the landslides can be determined.

Second, the maps may be useful for planning future subsurface investigations. Many past borings in these landslides were located near boundaries, and consequently may have indicated unrealistically shallow landslide thickness. Future borings can be placed well within the landslide boundaries indicated on plate 1, providing a better portrayal of landslide thickness.

Third, the maps should be helpful in planning remedial measures. Boundaries and major features of the landslides, shown in plate 1, define the moving masses of earth that are damaging structures in the Woodlawn area. This basic information is helpful for remedial measures because it defines, for the first time, the kind and scale of movement that is affecting the area, and shows how local expressions of damage are indications of the overall movement of each of the landslides. Plate 2, the map of styles of deformation, may be particularly helpful in planning remedial measures. This map is, to our knowledge, the first of its kind. We have prepared this map specifically so that knowledge of the styles and patterns of deformation in different parts of the landslides can be used for improved methods of investigation and stabilization.

LIMITATIONS OF THE MAPS

Several factors affect the accuracy of the information on the maps in plates 1 and 2. First, the maps reflect only the damage that was visible during the period of mapping. Much damage has been repaired as it occurred, and such repairs have obscured some of the evidence for boundary locations and deformation. Evidence was particularly difficult to obtain in the areas near the intersections of Lanikaula Street and Woolsey Place and of Lanikaula Street and Kalawao Street (pl. 1).

Features shown by solid lines on the maps are plotted to within about 10 ft (plus or minus) of their true locations on the ground (0.1 in. on the maps). This margin of error results from several factors, including uncertainties in location of property lines, use of pacing to determine locations, and possible minor distortions during photographic enlargement and reduction of the maps. Landslide features are dashed on the maps where their positions were determined only approximately, shown by fine dashed lines where the features are incipient or weakly developed, and queried where their existence is uncertain.

Features on the maps are plotted relative to readily identifiable indicators of property lines, such as walls or stakes, even though some property boundaries are known to have been displaced several feet from their map position by landslide movement. To plot the various features, we assumed that the property markers were in their correct positions with respect to the base map.

Finally, note that the maps do not delimit all areas of present or potential damage. Man-made structures and natural ground outside the perimeters of the landslides have been deformed as a result of movement that is probably related to the landslides. Furthermore, the extent of damage to structures within the perimeters of the landslides varies significantly. Thus, plates 1 and 2 show locations of the principal features of the landslides, but they do not indicate the severity of current or potential damage.

THE LANDSLIDES

Of three landslides that make up the landslide complex, two (the Hulu-Woolsey and Woolsey Place landslides) are physically connected as a single major landslide (pl. 1). Furthermore, the Alani-Paty landslide comes within 30 ft of joining the Hulu-Woolsey landslide in the backyard of 3098 Lanikaula Street. Adjoining these would physically connect all three landslides, but a definitive pattern of damage revealing such a connection is lacking.

Although two of the three landslides are physically separate, the landslides appear to be similar in many respects. The landslide material is a dark gray, clay-rich colluvium containing numerous clasts of volcanic rock. Concentrations of boulders that may be related to past landslide or flood activity occur at the ground surface in different parts of the landslide. The landslide material appears to consist of soft colluvium (blow counts typically less than 30) that overlies stiff colluvium. On the basis of limited subsurface data[1], we estimate that the Alani-Paty landslide averages about 25 ft thick and that the Hulu-Woolsey is perhaps 20 ft thick. The Woolsey Place landslide has been largely removed and was perhaps 15 ft thick. Note that these estimates of thickness, as well as estimates of volume based on them, are only rough approximations and should not be regarded as definitive.

Landslide description requires use of a few specific terms, such as head, toe, and flanks. Figure 4 illustrates and defines the meanings of these terms.

Alani-Paty Landslide

The Alani-Paty landslide is the northernmost landslide in the complex (pl. 1). The head of the landslide is scalloped or cuspate in shape. The uppermost parts of the cusps (near 3103 and 3081h) coincide with swales that extend up the steep slopes above the landslide.

The main body of the Alani-Paty landslide includes about 8.2 acres; if it averages 25 ft thick, the volume is about 330,000 yd^3. Elevation of the head and toe are about 375 and 170 ft, respectively. The length is about 1,000 ft and the maximum width is about 550 ft. Overall slope angle is about 12^{o}; the slope is significantly steeper in the upper part, so the slope profile is concave upward. There are 60 lots affected by the main body of the landslide.

Damage to structures in the head of the landslide results from stretching and sagging. Sagging is particularly obvious on the uphill side of the intersection of Alani and Paty Drives. Along the flanks of the landslide, structures are offset laterally, without much differential vertical movement. Such slope-parallel displacement along landslide flanks generally indicates that the failure surface is about parallel to the average ground surface. Lateral offset of 8.5 ft is present along the north flank in the wall on the uphill side of 3092 Kahaloa Drive. On the south flank of the landslide, the curbline of Kahaloa Place is offset laterally about 5.5-6 ft. Beginning at about 3089 Kahaloa Drive and continuing to the downslope limit of observable damage, the structures within the main body of the landslide are being shortened (compressed).

There is a large step in the north side of the landslide that extends from the flank at 3092 Kahaloa Drive to 3077 Lanikaula Street. The width of the landslide is decreased by this step from about 550 ft upslope of the step to about 350 ft downslope of the step. Downslope from 3077 Lanikaula Street, the north flank continues as a shear fracture to 3038 Lono Place. From there, a toe extends across several lots to near the intersection of Kalawao and Kaloaluiki Streets (pl. 1). The south flank joins the toe at 3069 Kalawao Street.

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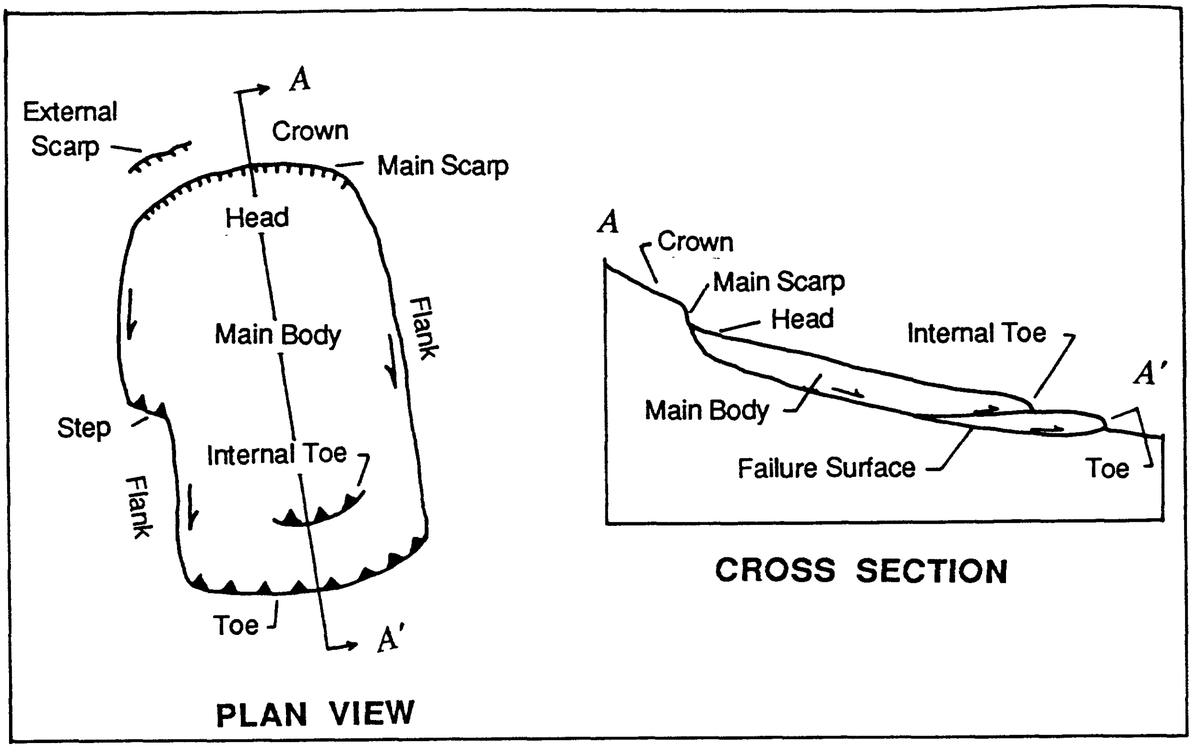
[1]Subsurface data in reports prepared by consultants for the City and County of Honolulu were provided to us by the Department of Public Works.



NOMENCLATURE

Main Scarp--A steep surface on the undisturbed ground around the upper periphery of the slide caused by the movement of slide material away from the undisturbed ground. The projection of the scarp surface under the displaced material becomes the failure surface.

Crown--The material that is still in place or practically undisplaced and adjacent to the highest parts of the main scarp.

Failure Surface--The surface or surfaces on which movement occurs.

Head--The upper parts of the slide material immediately adjacent to the main scarp. Deformation is by stretching and sagging.

Main Body--That part of the landslide that overlies the failure surface between the main scarp and the toe.

Toe--The margin of displaced material most distant from the main scarp. Deformation is by shortening or compression.

Flank--The side of the landslide. Deformation is principally by shearing.

Step--Offset of a landslide boundary, usually along a flank.

Figure 4. Plan view and cross section of a hypothetical landslide showing nomenclature of parts of a landslide. Modified after Varnes, D.J., 1978, Slope movement types and processes, Chapter 2 *in* Schuster, R.L., and Krizek, R.J. (editors). *Landslides--Analysis and Control*: Transportation Research Board Special Report 176, National Academy of Sciences, Washington, DC, p. 11-33.

Outside the main body of the landslide, there are three areas of systematic deformation that may represent sites for enlargement of the landslide (pls. 1 and 2). In the head, small scarps have formed in lots 3093, 3103, 3111, and 3119 Paty Drive that can be traced into cracks in the blacktop on Paty Drive. In April 1989, we found systematic evidence of distress to structures to the north of the landslide (pl. 2). Near the toe, compression on the downslope side of Kalawao Street has deformed a wall around a residence on the corner of Kalawao and Kaloaluiki Streets (lot 3170). If the main body of the landslide were to move several more feet, we expect that these areas of deformed ground would experience increased damage even if they remain outside the limits of the main body of the landslide.

Hulu-Woolsey Landslide

The Hulu-Woolsey landslide is the middle of the three landslides (pl. 1). Like the Alani-Paty landslide, it has a cuspate head in which two cusps coincide with swales in the steep slopes above the landslide area. Vertical displacements of about 3 ft are typical in the head area. Farther downslope, in the main body of the landslide, there has been much repair work to houses, streets, and curbs. Homeowners, however, report lateral displacement of 6 ft measured by surveying at a property line midway between Woolsey Place and Lanikaula Streets. Along the lower part of Woolsey Place and along Lanikaula Street, accurate measurements of displacement are not possible because of repairs, but it appears that lateral offsets are about 3 ft. Amounts of displacement decrease farther downslope until, at the toe, the offset of structures is 18 in. or less.

Damage to structures uphill from Hulu Place and Woolsey Place in the head of the landslide consists of stretching and pulling apart. Some houses, as at 3055 Woolsey Place, have been rotated because a corner of the house was outside the main body of the slide while the remainder of the house was displaced downslope. More typically, concrete garage slabs are pulled apart and the driveways sag. Along the flanks, structures are displaced by shearing, but the amounts of displacement have been obscured by repairs in critical areas.

Beginning with homes on both sides of Lanikaula Street and continuing downslope to the toe, deformation is indicative of shortening (compression). Features such as sidewalks and driveways are good references for displaying this style of deformation because they are relatively rigid and incompressible. Where the hillslope is being shortened by compression, the deformation can be absorbed in soil without any visible change, but a concrete driveway will transmit the entire deformation to its ends, where it is pushed into the street or the garage. Strains smaller than 0.5 percent can be readily detected and measured in such places.

The Hulu-Woolsey landslide is about 650 ft long and as much as 950 ft wide. The elevation difference between head and toe is about 120 ft (290 to 170 ft elevation); thus, the average slope is about 10.5°. The slope is steepest at the head and gradually flattens downslope, creating a concave-upward profile. The surface area of the main body of the landslide (not including the Woolsey Place landslide) is about 8.0 acres. If the thickness averages 20 ft, the main body of the Hulu-Woolsey landslide contains about

26,000 yd^3. There are about 62 lots involved in the main body of the landslide (66 lots including the Woolsey Place landslide).

Overall, the Hulu-Woolsey landslide has moved a little less over a longer period of time than the Alani-Paty landslide. The landslide features are more difficult to locate in the head and along the flanks of the Hulu-Woolsey landslide. In the head region, there are large undulations in Woolsey Place near lot numbers 3044-3066 that cannot be precisely correlated to damage to private property on either side of the street. Nonetheless, the perimeter of the head of the landslide is well located.

The flanks of the Hulu-Woolsey landslide are obscure downslope from a line connecting the intersection of Woolsey Place and Lanikaula Street with the toe of the Woolsey Place landslide in the rear of lot at 3015 Lanikaula Street (pl. 1). The south flank from the rear of lot 3015 presumably connects with a well-developed toe at the sidewalk in front of 3005 Kalawao Street, but there are few structures in this area to reveal the location of the flank. The toe at 3005 Kalawao dies out downslope from the house sitting on the lot, but no lateral offset or evidence of shearing was observed in the house. Up the slope, dense vegetation obscures any landslide features that might be present south or west of the Woolsey Place landslide. The north flank of the Hulu-Woolsey landslide extends roughly from the north end of the toe (behind 3098 Lanikaula Street), across 3092 Lanikaula to the south side of the intersection of Lanikaula Street and Woolsey Place. The house at 3098 Lanikaula appears to be undeformed, but the house at 3092 Lanikaula has been deformed in a manner consistent with right-lateral shear. Right lateral shear is evident in the fence at the north end of the toe (pl. 2), and the segment of the north flank that extends across Woolsey Place from 3093 Woolsey to 3087 Lanikaula is evident in aerial photographs of the area dated March 25, 1988.

Note on plate 1 that there is deformation on the downhill side of Kalawao Street, beyond the toe of the landslide. This deformation consists of a very slight (perhaps 2 in. in 100 ft) bowing of the curb, across the street from the toe of the landslide. We do not consider it likely that this deformation represents potential enlargement of the landslide to include the downhill side of Kalawao Street.

Woolsey Place Landslide

The Woolsey Place landslide is physically connected with the Hulu-Woolsey landslide by a scarp in the rear of 3033 Lanikaula Street, and thus is not a separate landslide. However, during the period surrounding the New Year's Eve storm of 1987-88, this landslide moved more rapidly than the larger Hulu-Woolsey landslide. Apparently, the Woolsey Place landslide moved on a separate, more shallow failure surface and created a distinct set of cracks and bulges around its margin. Thus, we describe the Woolsey Place landslide separately from the Hulu-Woolsey landslide. It is the smallest of the three, being only about 140 ft from head to toe and 230 ft in width parallel to the slope. The elevation difference between head and toe is 45 ft (270 to 225 ft elevation); the average slope is 18°. When we mapped the landslides early in 1989, a crib wall was being constructed along the downslope side of Woolsey Place, in the head of the landslide.

The landslide contains about 0.6 acres. If the average thickness is 15 ft, the main body contains about 15,000 yd^3. The main body of the landslide covers all or part of ten lots.

We know little of the extent and nature of the Woolsey Place landslide because the ground surface has been completely regraded and the landslide debris at least partially removed. Furthermore, much of the damage immediately downslope from the inferred position of the toe has been repaired. Displacements farther downslope from the toe are small, because no flank cracks could be found along Lanikaula Street nor to the south of it. There is evidence of shortening extending downslope from Lanikaula Street to Kalawao Street, but the pattern of damage is scattered and apparently related to movement of the Hulu-Woolsey landslide.

Pattern of Deformation

Plate 2 contains a summary of the data we collected on ground deformation in and around the landslides. There is a symbol on the map at each location where we were able to unequivocally determine that the landslide had stretched, shortened, or sheared. The data from plate 2 have been summarized in figure 5 to show the general parts of the Alani-Paty and Hulu-Woolsey landslides that are stretching, shortening, or being displaced without significant deformation.

In the interval between our field mapping and field checking (February 4-April 18), parts of the Alani-Paty landslide have moved significantly. Shear fractures having left-lateral displacements of a few inches in lots 3104, 3110, and 3118 Kahaloa Drive during January had displacements of as much as 2.5 ft in April. Shortening at 3091 and 3092 Kahaloa Drive has produced several toe-like features. An inclinometer at 3110 Kahaloa Drive that formerly was offset at about 25 ft is now also offset at a depth of about 10 ft. This greatly increased activity in the north part of the Alani-Paty landslide has obscured or destroyed the nondeforming band. The presence of at least two failure surfaces here greatly complicates the mechanics of this part of the landslide.

Displacement

The area of maximum displacement generally coincides on the landslide with the position of the nondeforming band. Stretching occurs upslope from the area of maximum displacement, and shortening occurs downslope from the area of maximum displacement. We obtained crude measures of displacement at different parts of the landslides by measuring offsets of walls, curbs, and other manmade structures. These offsets are indicated on plate 2. At many places, the offsets could be measured nearly parallel to the direction of displacements and are accurate to within a few inches. At some places, the offsets are somewhat less than the true displacements because offsets had to be measured oblique to the direction of movement; these are shown as lower-bound estimates on plate 2.

Along the perimeter of the Alani-Paty landslide, displacements are approximately 3-4 ft in the head, 6-10 ft along the flanks upslope from the

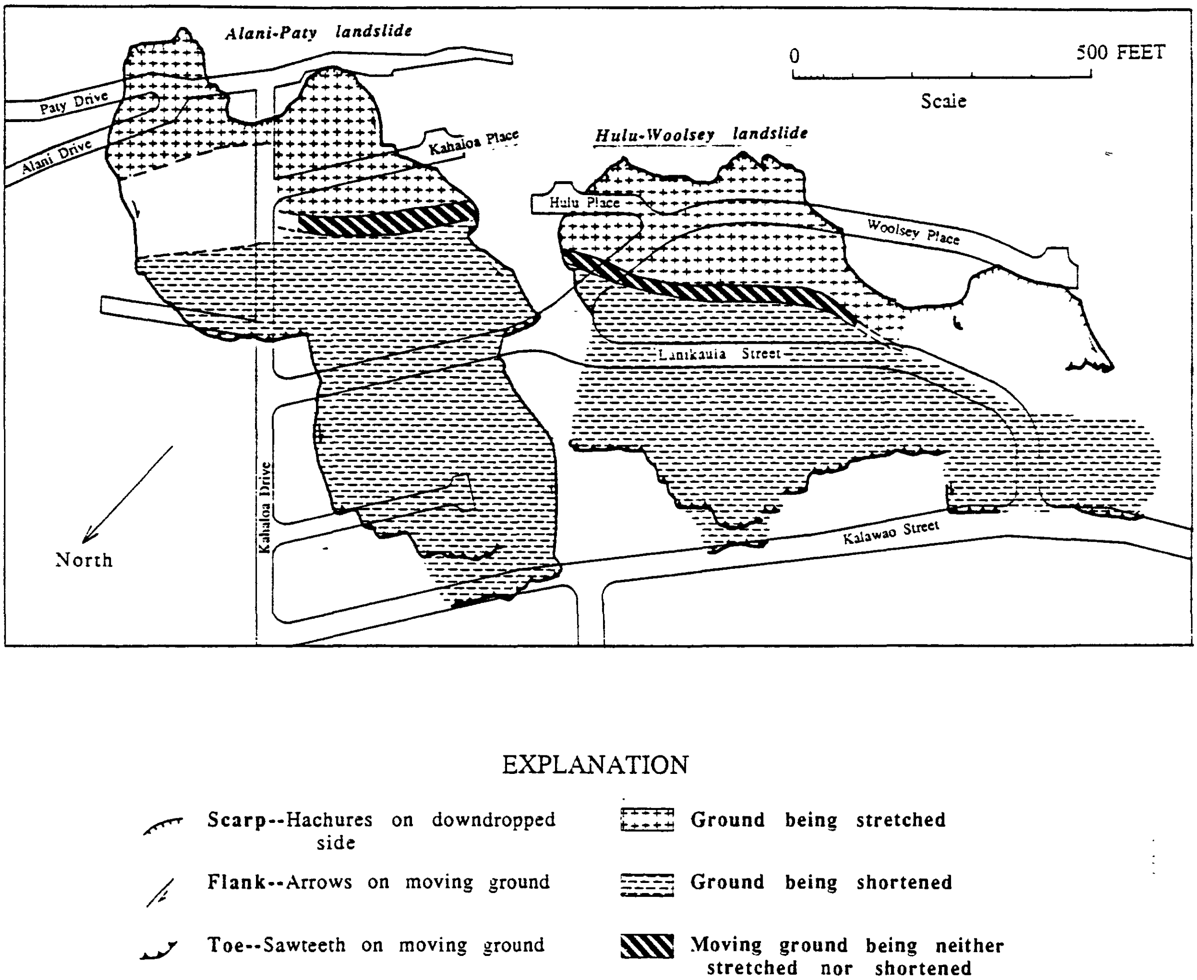


Figure 5. Map showing pattern of deformation of parts of the Alani-Paty and Hulu-Woolsey landslides. The areas of dark, diagonal stripes represent ground that is being neither stretched nor shortened. Deformation in the Alani-Paty landslide north of Kahaloa Drive is complex due to the development of several internal left-lateral shear fractures there. The existence of two failure surfaces, one 10 ft deep and the other about 25 ft deep, near the intersection of Kahaloa Drive and Kahaloa Place indicates that the pattern of deformation in this part of the Alani-Paty landslide might be even more complex than indicated by the shear fractures. Data on deformation in the southern part of the Hulu-Woolsey landslide are insufficient to completely characterize the pattern of deformation there.

step, and 3-6 ft along the flanks downslope from the step. Displacement decreases further in the toe. At the Hulu-Woolsey landslide, displacement is as much as 5 ft in the head, about 6 ft along the north flank at the back wall of 3084 Hulu Place, and diminishes significantly between Lanikaula Street and the toe. On the south flank of the Hulu-Woolsey landslide, displacements are not simple. Because the south flank of the Hulu-Woolsey landslide coincides with the overlying Woolsey Place landslide, measurements of displacement contain the combined movement of both landslides. The general pattern on the flank is increasing displacement from the head to a maximum of more than 20 ft and abruptly decreasing in the region of the toe of the Woolsey Place landslide. Downslope from the toe of the Woolsey Place landslide, the amount of displacement is insufficient to clearly define the location of the flank of the landslide.

The displacement data support the data derived from damage to structures. In places where we were able to measure displacement, we find a gradual increase in amount of displacement downslope from the head to a maximum, which occurs, generally, in the nondeforming zone. Farther downslope, the displacement diminishes toward the toe.

Potential for Enlargement

Evaluation of the likelihood of enlargement of these landslides, and identification of additional areas likely to become involved in landslide movement, is a speculation based on qualitative evaluation of existing field data and is very different from the documentation of factual conditions presented so far in this report. There are two lines of evidence, however, that are significant to the question of enlargement. The first is the features mapped beyond the boundaries of the landslides in plate 2. These features suggest the beginnings of enlargement because they indicate deformation consistent with the deformation caused by nearby landslide movement; that is, they indicate where stable ground is beginning to move in a manner similar to nearby parts of the landslide. We cannot be certain that these features will lead to enlargement of the landslides, but they do indicate the influence of the landslides on adjacent ground, and thus probably define the areas most likely to be incorporated if the landslides enlarge.

The second line of evidence relevant to enlargement is the map pattern of the landslides themselves. The separation of the landslides, the incomplete expression of boundaries, the irregular steps and turns in the boundaries, and the major step in the north side of the Alani-Paty landslide all suggest an immature landslide complex that is in the process of developing into a simpler, more mature form. The simpler form would include the currently stable ground between the landslides as well as the most likely areas of potential enlargement discussed above.

ACKNOWLEDGMENTS

We appreciate the cooperation of officials in the Department of Public Works, City and County of Honolulu, and we particularly thank Sam Calejo and his staff for their interest and support of this study. In addition to providing a base map for our work, they have allowed us to review the landslide data obtained by other workers. We also appreciate the patience and cooperation of the residents of the area, who offered much valuable information in addition to allowing us to examine and map their properties. We thank Dr. Paul Hummel of the Civil Engineering Department, University of Hawaii, for freely sharing ideas about the landslides, and William Meyer and his staff of the U.S. Geological Survey, Water Resources Division, for their administrative assistance.