Blocksliding on Schist in the Lower Redwood Creek Drainage, Northwest California

Ronald Sonnevil, Randy Klein, Richard LaHusen,
Darcia Short and William Weaver

ABSTRACT

Mass-movement is an important process for shaping landforms and producing sediment in the Redwood Creek basin, northwest California. Previous *investigations, based on analysis of aerial photographs, depict an abundance* of ancient and recent landslides on sedimentary terrane, but relatively few landslides in the heavily timbered schist terrane. This study, based on field mapping in the lower Redwood Creek basin, has identifed at least 33 active block slides on forested land underlain by the Schist of Redwood Creek. Most of the block slides occur immediately west of the Bridge Creek lineament.

Most block slides in the study area are discrete, translational landslides ranging in size from 0.4 to 2.0 hectares. Some of the larger features, which are not bounded by well-defined lateral scarps, range up to 40 hectares in areal extent. Episodic movement of the monitored block slides is closely related to rainfall events. Total annual measured displacement ranges from 0 to 7 meters. Observed depths to failure surfaces range between 3.4 and 6.9 meters. Nearly all block slides are associated with a highly sheared, black schist which is a metamorphosed argillaceous rock. Block-slide movement has been detected near the boundary between sheared black schist and overlying brownish-gray regolith. This preferential failure surface development is probably a result of permeability and cohesion differences between these materials.

Block slides differ from typical grassland-covered earthflows on Franciscan sedimentary terrane in northwest California. Major differences include size, morphology, lithologic controls on failure depths, and temporal characteristics of movement.

Blocksliding may be an important process responsible for sculpting schist terrane, producing many of the smaller, "trough-shaped" first-order drainages common to this lithologic unit within the lower Redwood Creek basin. Block slides also probably exist on schist terrane in the upper two thirds of the basin. Aside from along the Bridge Creek lineament, block slides are most likely to be found in other areas where the bedrock consists predominately of sheared black schist. They may also be found on terrain underlain by lithologies similar to the Schist of Redwood Creek, such as the South Fork Mountain Schist in northwest California and the Colebrooke Schist in southwest Oregon.

INTRODUCTION

Redwood Creek, a 730km^2 drainage basin in northwest California (Fig. 1), contains some of the most rapidly eroding terrain in North America (Janda and Nolan, 1979). Rapid tectonic uplift occuring within the last two million years has resulted in over 600 meters of stream incision along Redwood Creek (Kelsey, in press). The basin is underlain by highly sheared sandstones, mudstones and schists of the Franciscan assemblage (Harden and others, 1981). The deep incision combined with inherently unstable bedrock, seasonally high rainfall and extensive timber harvesting has resulted in abundant mass-movement activity. The dominate types of mass-movement are streamside landslides, debris slides, earthflows, blocksliding and soil creep (Harden and others, 1978; Swanston and others, 1983). Coleman (1973) reports that at least 36 percent of the Redwood Creek basin consists of landforms indicative of ancient or recent mass-movement activity.

Past work within the Redwood Creek basin indicates that landslide forms occupy three times as much area on sedimentary terrane as compared to areas underlain by schist, even though both rock types comprise equal portions of the catchment (Nolan and others, 1976; Harden and others, 1978). The dominant types of active or recently active landslides occurring within sedimentary terrane are earthflows, debris slides and streamside landslides. Although some streamside landslides and large debris slides are present in the schist (Kelsey and others, in press), previous investigators found few active, slow moving, deep-seated landslides (failure depths > 3m) equivalent to the earth flows on sedimentary terrane (Nolan and others, 1976). Instead, creep and blocksliding which occur over large, undefined portions of hillslopes and lack distinct boundaries, have been shown to be important mass-movement processes on areas underlain by schist bedrock (Swanston and others, 1983; Marron, 1982).

Estimated erosion rates from landslides and gullies can account for much of the sandstone-derived sediment in Redwood Creek, but available data concerning erosion rates for schist terrane cannot account for a substantial portion of the schist-derived sediment (Harden and others, 1978; M. Madej, personal communication, 1985). This discrepancy caused Harden and others (1978) to speculate that landsliding in schist terrane must be much more prevalent than was obvious on the aerial photographs used for the basin-wide landslide distribution analysis by Nolan and others (1976).

Studies now in progress within the lower Redwood Creek basin have documented two additional mechanisms of landsliding which may help account for more of the schist-derived sediment. LaHusen (1984), and LaHusen and Sonnevil (1984) documented an abundance of road-related debris flows occurring in schist terrain. Additionally, in our recent work in selected areas of the lower watershed, we have identified 33 active deep-seated translational landslides occurring on schist. Because they are forested, most of these slow moving landslides were not apparent on the small-scale aerial photographs used by previous workers. Preliminary results on the spatial distribution and movement characteristics of a sample of these 33 earth block slides (after Varnes, 1978), herein referred to as "block slides", is the subject of this report.

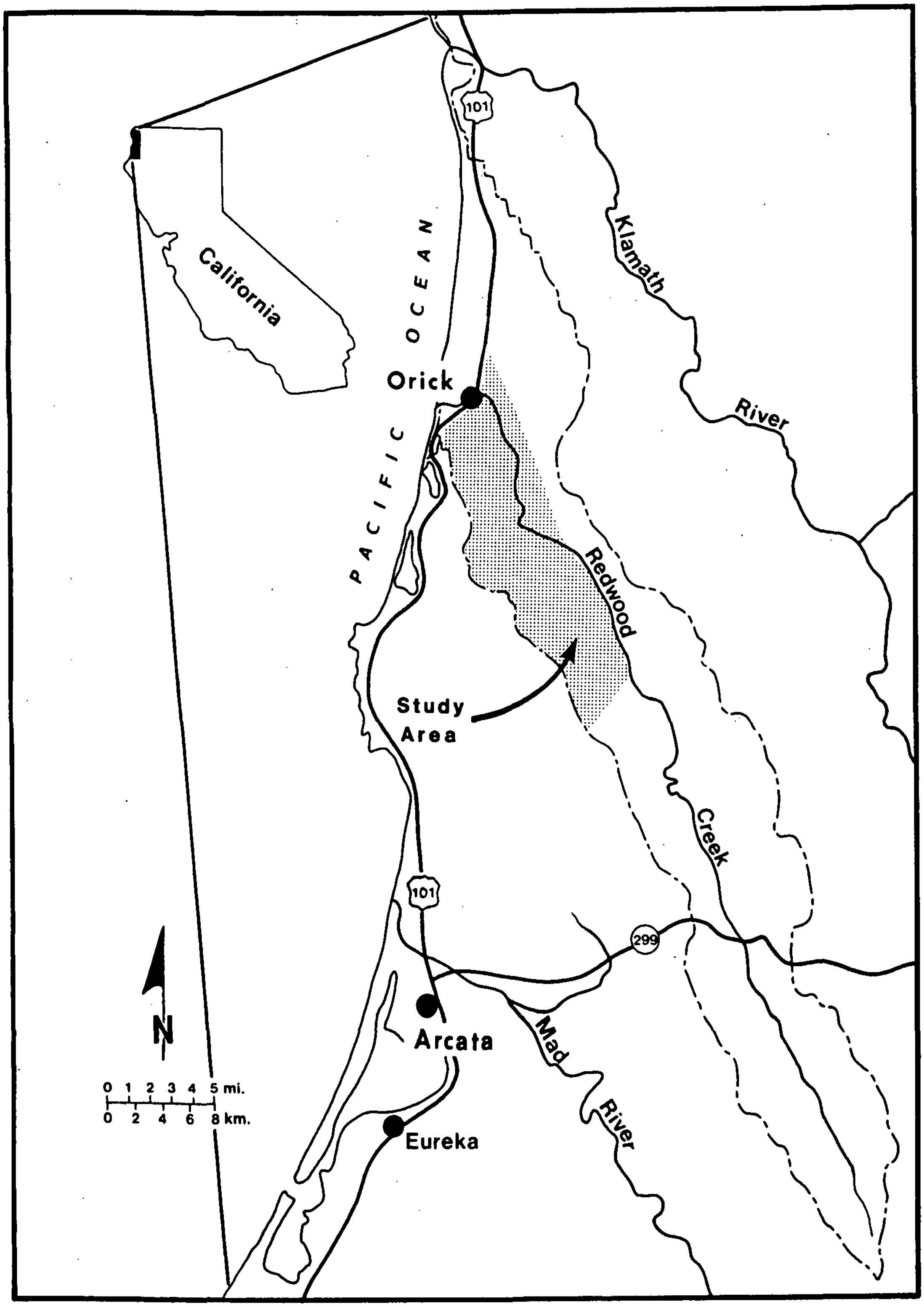

Figure 1. Map of the Redwood Creek basin showing location of study area.

CHARACTERISTICS OF BLOCK SLIDES

We have tentatively divided the block slides into two categories: 1) those comparatively small, discrete features with distinct lateral boundaries, and 2) larger features which do not have distinct lateral boundaries (Fig. 2). Most of the information for this preliminary report concerns the smaller discrete block slides.

Distribution

The study area (Fig. 1) includes that portion of the Redwood Creek basin, contained within Redwood National Park, which is underlain by the Schist of Redwood Creek. Figure 2 shows the distribution of known active block slides within the study area. Most of these landslides were discovered either by geomorphic field mapping (scale=1:1200) conducted prior to watershed rehabilitation projects or because they offset roads. A few of the landslides were identified during previous studies (Coleman, 1973; Nolan and others, 1976). Although some of the features shown in Figure 2 could be seen on aerial photographs or during low-altitude aerial reconnaissance, most were not identifiable due to the presence of trees. Additional features probably exist in non-roaded portions of the study area which have not yet been mapped.

Morphology

The discrete block slides investigated range in size from 0.5 to 2.0 hectares (Fig. 3). Widths of the landslides vary from 35 to 60 meters while slope lengths vary from 100 to 275 meters. Main scarp heights vary from 1 to 5 meters. Typically, lateral scarps are nearly vertical and range from less than 1 meter to over 3 meters in height. Gullies often form at one or both lateral scarps. Some of the landslides are flanked by less steep, vegetated, older lateral scarps which vary from one meter to over 10 meters high. Ground surface inclination on the landslides is commonly between 15 and 30 degrees.

The discrete block slides consist of one or more coherent blocks separated by minor scarps (Fig. 3). There is a tendency for those blocks farthest downslope to be more disrupted and exhibit characteristics indicative of internal deformation. Two of the block slides studied are highly disrupted and show evidence of a large component of flow in their movement. According to Varnes (1978), these complex slope movements, which appear to have a large component of flow, should be termed block slide - earth flows. However, for simplicity, all of the landslides shown in Figure 2 are referred to as block slides.

The larger, less discrete block slides involve up to 40 hectares of hillslope and are not bounded by well-defined lateral scarps. Ground surface inclination is more variable, ranging from 5 to 40 degrees. Although sometimes present, discrete blocks are not as common as on the smaller features.

All of the block slides are forested. Those which are in an old-growth redwood - Douglas-fir forest have fewer standing trees and more rotten down-timber on their lower portions than on their upper portions. Individual blocks can often be recognized by differences in the concentration of standing

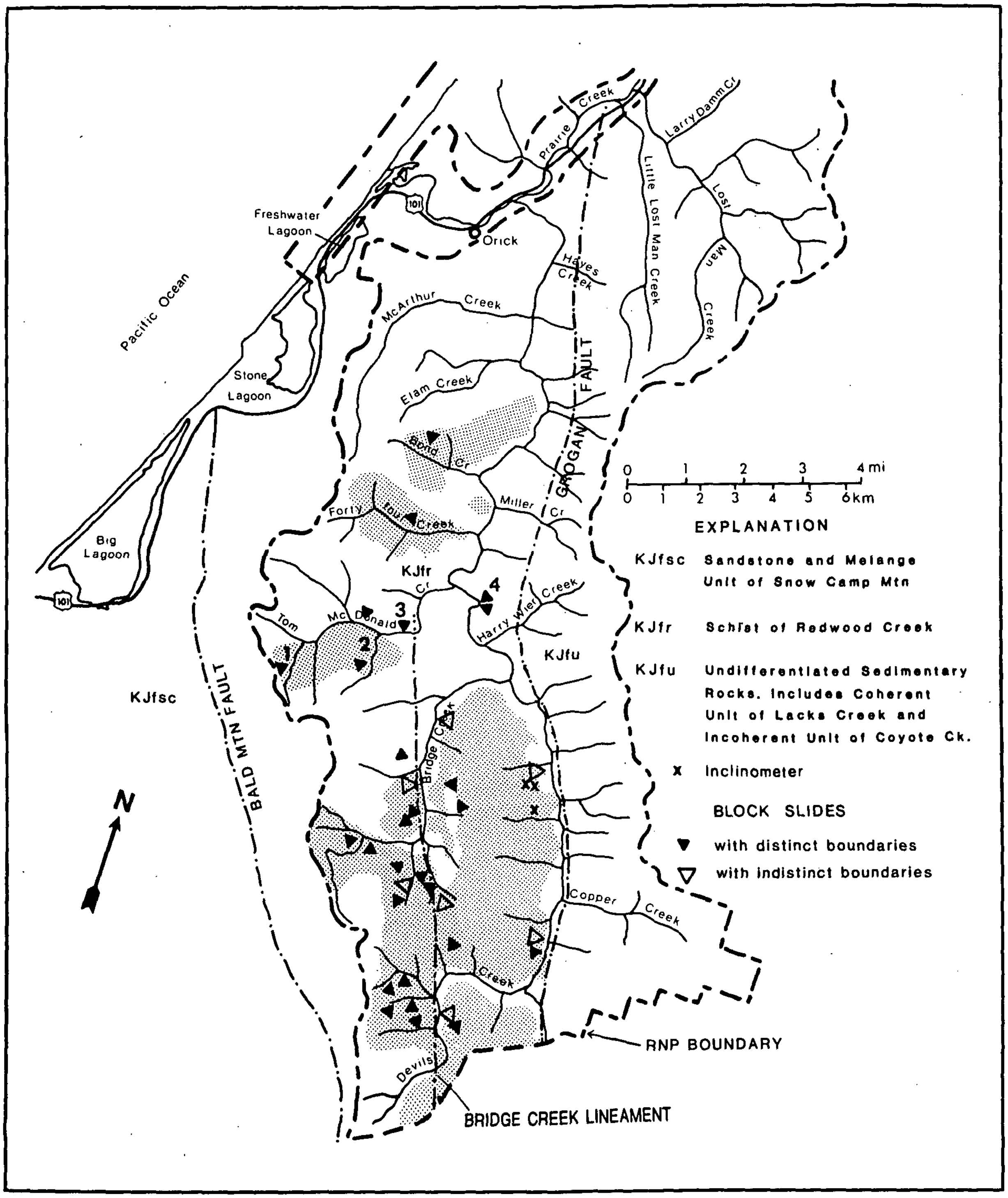

Figure 2. Generalized geologic map of the lower Redwood Creek basin (after Harden and others, 1981) showing known location of block slides. Stippled pattern shows those areas which have been field mapped at a scale of 1:1200. Numbered features are those referred to in text and Table 1: 1) Upper G-line Slide; 2) Lower G-line Slide; 3) Switchback Slide; and 4) Elbow Slide. Inclinometers shown are described by Swanston and others (1983).

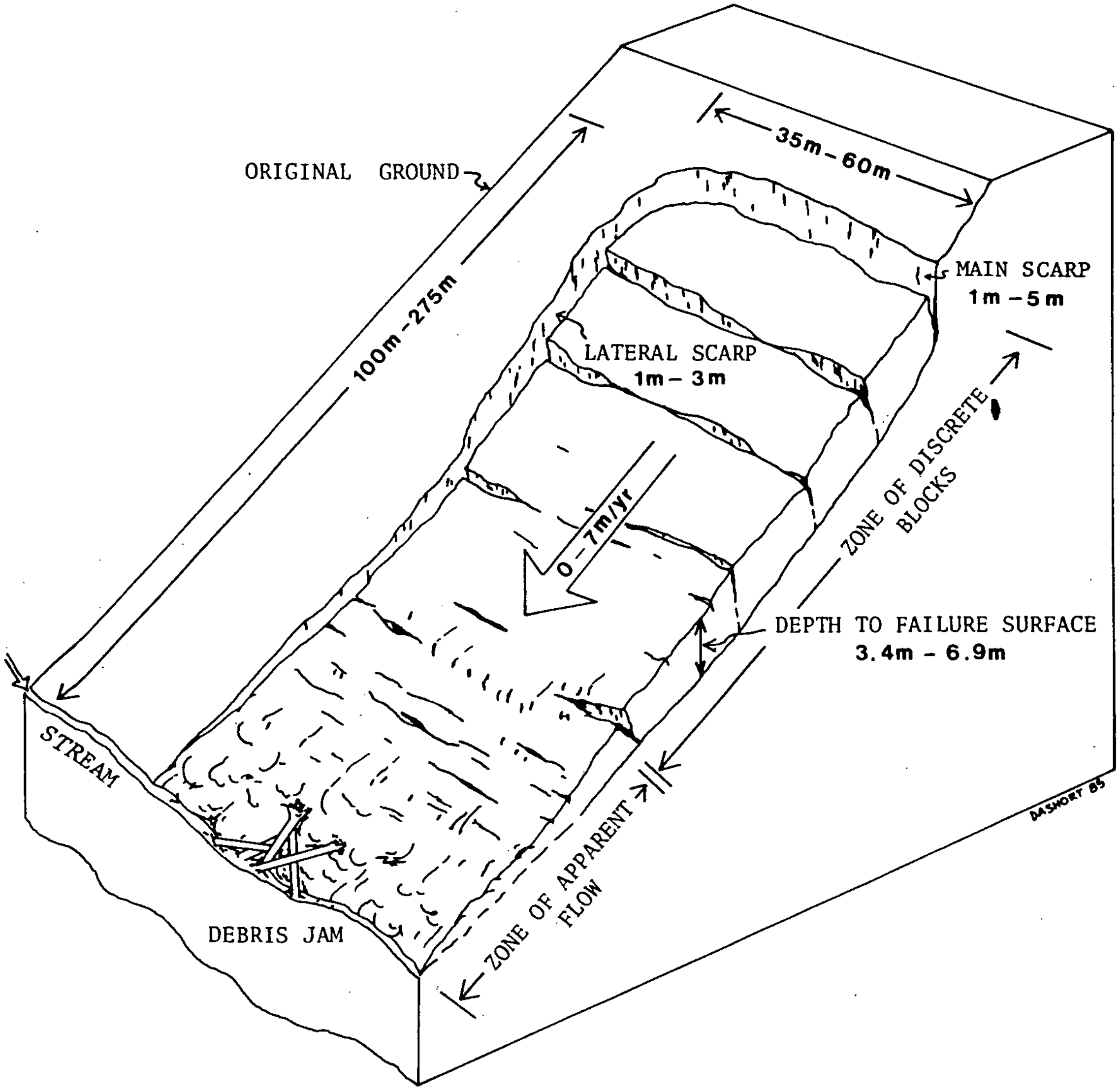

Figure 3. Schematic diagram showing salient features of a typical discrete block slide.

trees or rotten fallen trees. Evidently, landslide movement initiates low on the hillslope and progresses upslope in block-like fashion with time. On at least one of the features, progressive slope failure is expanding along lateral margins as well as upslope.

Where fallen timber has been introduced into a stream channel by block sliding, it may be transported away, as is the case with Redwood Creek's main channel. It may also result in debris jam formation if the stream power or channel width are insufficient to allow transport of this very large organic debris. Only one of the studied block slides has dammed a stream channel. Particle size analyses of soil and regolith samples suggest that about 40 percent of the sediment introduced into streams by block slides becomes bedload material (>2 mm diameter).

Lithologic Materials

Common to nearly all block slides is a highly sheared, black, albite-muscovite-chlorite-quartz schist with abundant carbonaceous material. More coherent, unsheared exposures of black schist are also common. This schist is a metamorphosed argillaceous rock. Although this material visually and tactually resembles a graphite schist, x-ray diffraction of six samples from different locations showed no graphite to be present. Similarly, Leathers (1978) did not find graphite in any samples collected from the Schist of Redwood Creek exposed along the Pacific coast between Big Lagoon and the mouth of Redwood Creek (Fig. 2). Overlying the sheared black schist is brownish-gray regolith containing abundant subangular clasts of a light-gray albite-muscovite-chlorite-quartz schist. Lenses of the sheared black schist are also present in this material, particularly near the basal contact. On the Switchback Slide (Table 1, Fig. 1), black schist material was not exposed at the ground surface but was discovered during drilling. The association of mass movement with sheared black schist is uncertain on a few of the block slides due to the absence of surface exposures and lack of subsurface drilling or trenching.

Failure Depths

Excessive episodic movement, limited funds, and poor accessibility to most of the block slides prohibits the use of conventional inclinometers to determine depths and styles of landslide movement. Alternately, depth-of-failure (DOF) indicators were installed with a portable drill rig. A DOF indicator (Fig. 4) consists of a 2.4 cm diameter PVC casing installed to a depth of seven to nine meters (the maximum depth attainable with the drill rig). A 20 cm length of steel rod attached to a stainless steel cable is lowered into the bottom of the hole. A similar size rod, attached to a measuring tape, is lowered from the top of the casing during periodic field inspections. If the bottom of the casing is below the failure surface and there has been sufficient movement and distortion of the casing to inhibit passage of the steel rods, the depths over which movement has occurred can be approximately determined (Fig. 4). The accuracy of determining failure zone thicknesses with DOF indicators is dependent upon the amount of movement which has occurred between installation and measurement, and dimensions (length and diameter) of the steel rod. The horizontal distance of movement which displaced the cased drill holes was not determined for this study.

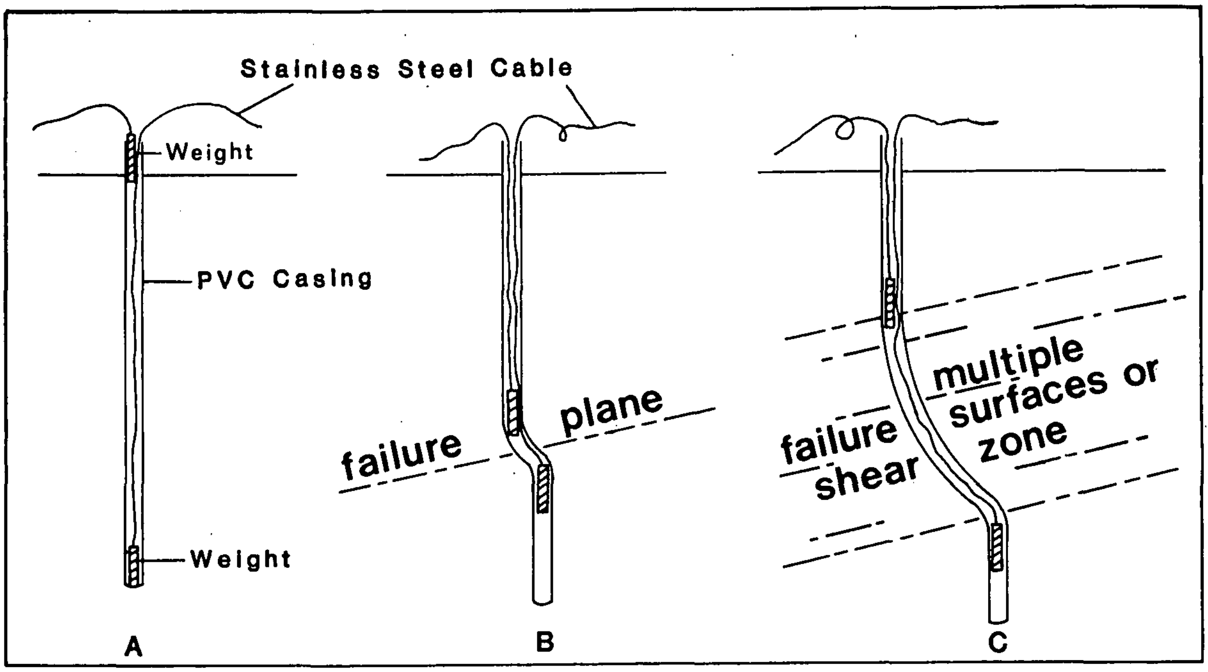

Figure 4. Schematic diagram showing depth-of-failure (DOF)indicator (A) before and (B or C) after movement.

Two DOF indicators were installed at separate locations on the Switchback and Lower G-line Slides (features 3 and 2, respectively, Fig. 2) in December, 1983. On the Upper G-line Slide (feature 1, Fig. 2), two separate pairs of DOF indicators were installed in November, 1983. One DOF indicator was displaced on the Switchback Slide and both pairs were displaced on the Upper G-line Slide during the 1983-84 winter (Table 1). At one of the locations on the Upper G-line Slide, the casings pinched during a two-week period between when the hole was drilled and when a rod was lowered into them, precluding an estimate of the failure zone thickness. The second (upper) pair of DOF indicators on the Upper G-line Slide showed inconsistent results. Although the lower constrictions in these two adjacent drill holes occurred at identical depths, the upper constrictions differed in elevation by 1.4 m, suggesting a wider zone of shear or multiple failure surfaces. These two upper G-line DOF indicators have since been obliterated by rehabilitation of the G-line road. The one DOF indicator which was displaced on the Switchback Slide suggested a narrow zone of shear. The remaining DOF indicator on the Switchback Slide and the two on the Lower G-line Slide were not offset enough to constrict the casing.

Black schist material was observed in the drilling effluent during installation of seven of the eight DOF indicators, however, it was impossible to tell if the schist bedrock was coherent or sheared. Table 1 lists the depths at which the marked color change from brown to black was observed in the drilling effluent. At two of the three locations with displaced

			Distance from Ground Surface to:			
Feature Number	Name	Depth-of-Failure Indicator	Upper Constriction	Lower Constriction	Distance Between Constrictions	Depth to Black Schist
1	Upper G-line Slide	UGU20	6.76m	6.94m	0.18m	0
1	Upper G-line Slide	UGU25	5.39m	6.94m	1.55m	0
1	Upper G-line Slide	UGL20	3.41m	-	-	3.8m
1	Upper G-line Slide	UGL25	3.99m	-	-	4.0m
2	Lower G-line Slide	LGID25	-	-	-	0
2	Lower G-line Slide	LGDF25	-	-	-	5.2m
3	Switchback Slide	SWBUP25	-	-	-	-
3	Switchback Slide	SWBLO25	5.59m	≦5.67m	≦0.08m	5.9m

Table 1. Summary results from depth-of-failure (DOF) indicators. DOF indicators UGU 20 and UGU 25 were installed at similar elevations approximately 7 meters apart. UGL 20 and UGL 25 were installed 4 meters apart at similar elevations. All DOF indicators ranged from 7 to 8 meters deep.

DOF indicators, displacement was near the upper boundary of the black schist. Displacement at the third locality occurred within the black material.

Movement

Surface movement is being monitored on portions of three block slides by stakeline surveys or continuously recording slope-movement indicators. The Upper G-line Slide and Elbow Slide (Features 1 and 4, Fig. 2) have continuously recording slope-movement indicators across a lateral scarp (Fig. 5). One movement indicator utilizes a solid state data recorder and the other records movement on a strip chart. The solid state data recorder on the Elbow Slide is set to record a minimum of 7.5 mm of movement and the strip chart recorder (on the Upper G-line Slide) is sensitive to approximately 4 mm of movement. Since monitoring of Elbow Slide began in December, 1984, no movement has been recorded. However, a total of 45 mm of movement on the Upper G-line Slide was recorded during seven separate time periods between February 1984, and March 1985. All recorded movement occurred in response to individual storms or storm sequences.

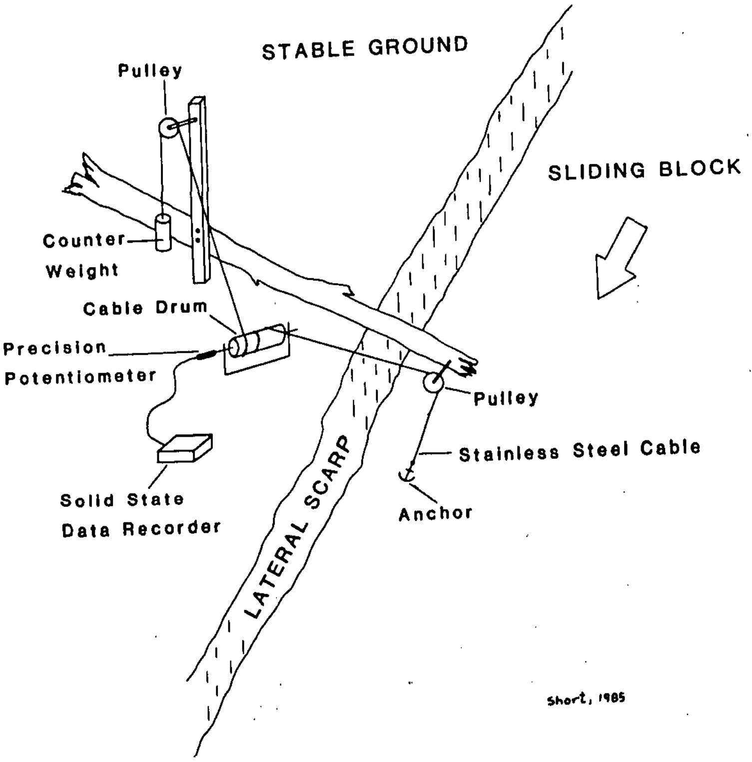

Figure 5. Diagram showing slope-movement-indicator installation on the Elbow Slide (feature 4, Fig. 2). On the Upper G-line Slide (feature 1) a strip chart recorder replaces the potentiometer and data recorder.

A stakeline was installed and measured with a theodolite and electronic distance meter on the Elbow and Switchback Slides in fall 1984, but neither have been remeasured yet. The stakeline across the Elbow Slide is located in the same area as a stakeline installed by the USGS in 1974 (Harden and others, 1978). They reported a maximum of 1.09 m of movement on the horizontal axis occurring between 1974 and 1976. Between 1976 and 1979, surveys showed an additional 0.55 m of movement (M. Nolan, written communication 1985). Our resurvey of the same stakeline in December 1984 indicates that at least 6.7 m of additional movement has occurred on the most active portion of the stakeline since 1979.

Other information concerning the timing and magnitude of movement for block slides is qualitative, consisting of field observations by National Park Service geologists. This information indicates that most movement occurs in direct response to prolonged, intense precipitation events or sequences of events. Movement of a very active, highly disrupted block slide was very responsive to rainfall during winter and spring 1983. Over seven meters of episodic movement occurred between late January and early April 1983 (Spreiter and Johnson, 1983). No movement has been observed on any of the block slides during the summer.

DISCUSSION

Controls on Block Slide Distribution and Depths of Movement

Although our investigation of block slides is at an early stage, some preliminary generalizations can be made concerning controls on their movement characteristics and spatial distribution. The most common characteristic of these features is the association with sheared black schist. On two block slides movement was detected near the boundary between the black schist and the overlying regolith with DOF indicators (Table 1). On a third block slide, the Elbow Slide, field observations indicate that movement is also occurring near or at this discontinuity in material types. Field observations suggest that cohesion is greater and permeability is less for the sheared black schist than in the overlying regolith. Presumably, the lower permeability impedes drainage into the sheared black schist, perching groundwater above it. The greater cohesion of the sheared black schist encourages failure surface development at this contact. Similar discontinuities in material properties occur at the boundary between coherent schist bedrock and overlying regolith on at least one block slide where sheared black schist was not found.

Most of the block slides identified occur in an elongate zone extending from Devils Creek to Tom McDonald Creek (Fig. 2). Within this zone, observations indicate that sheared and unsheared black schist comprises a greater proportion of the exposed bedrock than in schist terrane elsewhere in the park. This elongate zone (Fig. 2) is immediately to the west of the "Bridge Creek lineament", defined by Harden and others (1981) to coincide with aligned segments of Panther, Devils, Bridge and Tom McDonald Creeks. The lineament may be partially controlled by this concentration of highly sheared, easily eroded material. Future geologic mapping may show this black schist to be a distinct member of the Schist of Redwood Creek.

Comparison with Other Landslides

Swanston and others (1983) measured displacement along narrow shear zones at 5.5, 6.4 and 12.6 meter depths at three inclinometers located in schist terrane within Redwood National Park (Fig. 2). The two inclinometers which sheared at shallower depths are 10 m apart while the third inclinometer is 400 m to the south. The maximum movement they observed over a six-year period was small (16.4 mm/year). Their monitoring sites did not display scarps or other morphologic features typical of landslides, suggesting that the observed movement was of a more widespread, unconfined nature. We have observed much more rapid rates of movement (up to 7 m/year) occurring on block slides at depths comparable to one of the locations monitored by Swanston and others (1983). Perhaps the process is similar except that on block slides the blocks have detached from the hillslope and movement has accelerated substantially.

Large grassland-covered earth flows are a common type of mass-movement occurring in Franciscan sedimentary terrane in the Redwood Creek basin and elsewhere throughout northwest California (Nolan and others, 1976; Kelsey, 1978; Keefer and Johnson, 1983; Iverson, 1984). Characteristics of block slides which are also common to many earth flows include: 1) a predominately translational style of movement, 2) annual movement rates less than 10 m/year, 3) association with highly sheared argillaceous rock types (the black schist is metamorphosed mudstone), and 4) basal failure surfaces at approximately five meter depths.

Dissimilarities between earth flows and block slides also exist, and these are perhaps more important than their comparable characteristics. First, failure surfaces on block slides occur, at least locally, at lithologic boundaries (regolith/sheared black schist) whereas studies of earth flows have not identified lithologic contacts at basal shear zones (Keefer and Johnson, 1983; Iverson, 1984). Secondly, movement of block slides is episodic and appears to be uniquely associated with rainfall events whereas movement of some earth flows may persist from late fall to late spring and, in some instances, throughout summer (Iverson, 1984). Thirdly, although some earth flows are comparable in size to block slides, many earth flows are much larger, extending from major drainage divides to the valley bottom. Earth flows also commonly display more surficial evidence of slumping or internal deformation. Finally, most block slides lack the classic "teardrop" planimetric shape and sigmoidal profile characteristic of many earth flows.

Contrasts between movement of block slides and earth flows may be explained by differences in clay content of materials comprising the two types of failures. Particle size analyses indicate that block slides have an average of 14 percent clay in the <2 mm fraction (Sonnevil, unpublished data); about half the clay content of material comprising some earth flows on sedimentary terrane in the Redwood Creek basin (Iverson, 1984; J. Popenoe, personal communication, 1985). A higher clay content and associated lower permeability may increase retention of water and prolong the duration of movement.

Within schist terrane in the Redwood Creek basin, there are a large number of "trough-shaped" first-order drainages ranging in area from a few hectares to over a square kilometer. These have the appearance of having been formed by mass-movement rather than fluvial processes. Nolan and others (1976) identified some of these features and many more have been located by National Park Service staff during detailed geomorphic mapping. Significantly, most of the block slides we have found incorporate or originate in these first-order drainage basins, suggesting that this process may represent an important mechanism for sculpting morphologically similar drainages common throughout the schist terrane of Redwood Creek.

Lithologic units similar to the Schist of Redwood Creek occur elsewhere. Kelsey and Hagans (1982) have correlated the Schist of Redwood Creek with the South Fork Mountain Schist in northwest California which, in turn, is lithologically similar to the Colebrooke Schist in southwest Oregon (Coleman, 1972) (Fig. 6). Literature concerning styles of landsliding on these lithologic units is sparse. Buer and James (1976) discuss landslides within the eastern half of the South Fork Mountain Schist which have similarities to the block slides. D. Haskins (personal communication, 1985) suggested that the block slides in Redwood Creek may be analagous to some active subsidiary landslides associated with ancient translational/rotational landslides in schist on the east side of South Fork Mountain. Landslides occurring on the western slopes of South Fork Mountain, particularly those underlain by metamorphosed argillaceous rocks, may also be block slides (R. Farrington, personal communication, 1985).

SUMMARY AND CONCLUSIONS

Slow moving, deep-seated landslides on schist terrane in the Redwood Creek basin are more common than is evident from aerial photographs. Detailed geomorphic mapping within the lower Redwood Creek basin has delineated 33 active block slides overlying schist bedrock. Characteristics common to inventoried features include: 1) predominately translational movement, 2) areal extent varying from 0.4 to 2.0 hectares, but occasionally ranging up to 40 hectares, 3) episodic, storm-dependent movement with observed total annual displacement up to seven meters, 4) observed depths to failure surfaces ranging between 3.4 and 6.9 meters, and 5) association with a highly sheared black schist, which is metamorphosed argillaceous rock.

Block slides differ from earth flows which are common on Franciscan sedimentary terrane in northwest California. Block slides are smaller than most earth flows and lack the "teardrop" planimetric shape and sigmoidal profile characteristic to many earth flows. Depths to failure surfaces on block slides can be lithologically controlled, but studies of earth flows have not demonstrated controls on failure surface locations. Monitored block-slide movement is more episodic than movement on monitored earth flows. Movement differences may result from the amount of clay in materials which comprise these two landslide types.

The number and distribution of block slides in the lower third of the Redwood Creek basin suggests that additional features exist upstream of Redwood National Park, particularly along the Bridge Creek lineament or other locations where sheared black schist is abundant. Block slides may be a common form of mass-movement outside of the Redwood Creek basin in terrane underlain by lithologic units similar to the Schist of Redwood Creek (for example, the South Fork Mountain Schist in northwest California and the

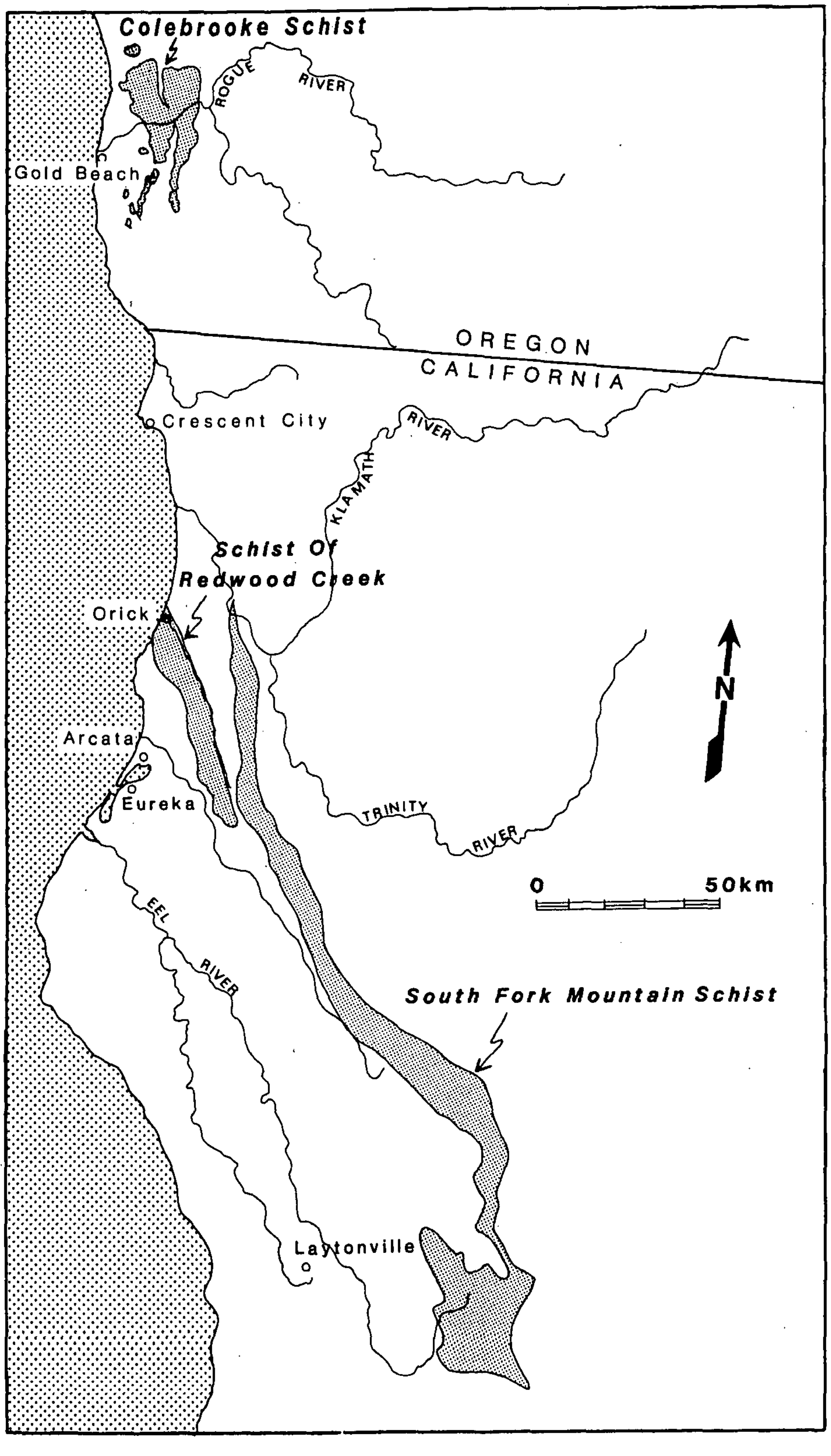

Figure 6. Map showing the distribution of the Schist of Redwood Creek, the South Fork Mountain Schist (Kelsey and Hagans, 1982) and the Colebrooke Schist (Coleman, 1972).

Colebrooke Schist in southwest Oregon). Because their movement occurs in small increments, block slides will not be major catastrophic sediment sources but, instead, represent a more persistent, long-term erosion process.

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