PRELIMINARY AGE CLASSIFICATION OF LANDSLIDES FOR INVENTORY MAPPING

By
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ABSTRACT

A preliminary age classification for landslides is proposed for inventory mapping, based on morphologic criteria visible on aerial photographs. Because landslide scars and deposits are generally disequilibrium landforms, they progress through observable morphologic stages as they age. Four age classes are distinguished: 1) active; 2) inactive-young; 3) inactive-mature; 4) inactive-old. Each age class reflects the age of latest movement only.

The morphologic "freshness" of each part of the landslide must be evaluated, including: the head scarp, lateral scarps, marginal drainage, internal scarps and blocks, internal drainage pattern, vegetation type and density, and toe morphology. Morphologic parameters defined from air photos are similar to the morphologic relative-dating (RD) parameters used for glacial deposits, which are also bouldery disequilibrium landforms (Burke and Birkeland, 1979). In addition, cross-cutting relationships between the landslide and other landforms are used for age estimation.

The proposed classification has limitations caused by both internal and external factors: 1) Aerial photographs have limited resolution in identifying such small features as tilted ("jackstrawed") trees; 2) Morphologic differences exist among landslide types, which can cause two slides of different type to appear similar, even if of different age; 3) Landslides on surfaces of different aspect or slope are modified at different rates by different dominant slope processes; and 4) It is commonly difficult to obtain absolute ages with which to "calibrate" the age classification.

INTRODUCTION

As used in this paper, landslide includes a broad range of "...slope movements wherein shear failure occurs along a specific surface or combination of surfaces" (Schuster, 1978, p. 2). Much current description of landslides concentrates on the type of movement, because movement type is the basis for present landslide classification (e.g. Varnes, 1978). However, for many applications, the age of a landslide is just as important as the mechanism of movement. Geologic-hazard analysis should be concerned with not only the location, and style, but also the age of any mass movement.

Currently there is no widely accepted age classification for landslides nor has the basis for such a classification been published. This paper is a preliminary attempt to define what factors should be considered in age categorization of landslides. The key principle utilized is that landslide movement creates a disequilibrium landform with anomalous negative and positive relief. Such features are modified through time from their initial state by weathering, erosion, and deposition, which progressively obscure the initial topographic anomalies.

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Many landslide deposits are identified on published geologic maps in the United States at various scales; hence, their locations are known, but little is known about their ages or types of movement. In future landslide-hazard analysis, one of the main goals should be to group such known (and newly discovered) landslides into age groups. Age grouping would allow a distinction to be made between active, dangerous slides and eroded and weathered, stabilized slides. Techniques summarized in this paper were derived during landslide inventory mapping on roughly 100,000 acres in the Teton National Forest, northwestern Wyoming, during the Summer of 1983.

PREVIOUS WORK IN ESTIMATION OF LANDSLIDE AGE

Standard descriptive works on landslides published before the 1960's contained little information on ages of landslides (Sharpe, 1938; Eckel, 1958). In the 1960's and 70's descriptive terms relating to landslide age were used informally within general works (Zaruba and Mencl, 1969; Leighton, 1976; Varnes, 1978),in regional landslide inventories (Schroder, 1967, 1971; Bailey, 1971), and in limited-area or single-slide inventigations (Berklund, 1977; Braddock, 1978; Piteau et al, 1978). Table 1 summarizes the terminology used by each author. Unfortunately, of the authors listed only Shroder (1967, p.34-44) gave a detailed list of morphologic criteria typifying each age subdivision. Age classes of some subsequent workers rely on absolute date(s) of slide movement, something often difficult to ascertain, especially at the inventory level.

TABLE 1
TERMINOLOGY OF PREVIOUS AGE CLASSIFICATIONS

Author	Date	Classification
Various European[1]	1940's - 1970's	Active versus fossil or ancient
Shroder	1967, 1971	Youth, maturity, old age (with modifiers late and early)
Leighton	1976	Active vs recently active vs inactive
Berkland	1977	Active (10 yr), recent (10-100 yr), old (100-100 yr), older (1000-10,000) ancient (10,000-70,000), pre-Wisconsin (70,000-3,000,000 m), pre- Quaternary (>3,000,000 yr)
Varnes	1978	Active (currently moving), suspended (>1 yr), inactive (>1 yr); inactive can be dormant (potential for movement) or stabilized (no potential for movement).
THIS PAPER[2]	1984	Active (historic), inactive-young, inactive-mature, inactive-old age.

[1]Zaruba and Mencl, 1969, Klengal and Pasek, 1974; Nossin, 1972; Popov, 1946

[2]Classification relies on features visible on aerial photographs. Absolute ages for each category will vary from area to area, depending on local climate and the intensity of weathering and erosional processes.

Papers describing the morphology of dated landslides, though few, are critical for initial calibration of any age classification. Stout (1969) compared a barely-modified slump about 3000 years old in Southern California with a nearby severely-dissected slide roughly 17,000 years old. Shroder (1967, 1971) cataloged the morphology of numerous landslides in Utah dated by historic records and by stratigraphic setting. Bailey (1972) contrasted the fresh morphology of the 1925 Lower Gros Ventre rockslide with the subdued topography of the adjacent 4300-year old Devil's Elbow Slide. Piteau et al (1978) examined the subdued morphology of a large complex slide older than about 6600 years in British Columbia which resembles the Devil's Elbow, Wyoming, slide. In Colorado, Braddock (1978) described numerous landslides of different appearance on the dip slopes of the Dakota hogback; ages of movement ranged from Pleistocene to pre-Miocene(?).

Knowing the age of a landslide can be crucial in determining its potential for renewed movement. Varnes (1978, p. 56) noted that for many older slides, "the factors essential to movement have been removed." Fluvial erosion of the upper body of the slide and/or depositional buttressing of the toe can act together to render a previously unstable slope stable, as noted by Stout (1969, p.177) for a Pleistocene landslide in California. In this respect an age classification can be useful in differentiating between slides where reactivation is probable, possible,or where it is unlikely due to subsequent modification.

THE GEOMORPHIC BASIS FOR LANDSLIDE AGE CLASSIFICATION

The concept of deterministic, unidirectional landform change with time was first applied to fluvial landforms in America by Davis (1899) in his grand "geographic cycle" of youth, maturity, and old age. Although later work has challenged Davis' assumptions and conclusions with respect to entire landscapes, the model of closed-system-type of slope decline at decreasing rates has recently been successfully applied to newly-made, disequilibrium landforms such as fault scarps (Wallace, 1977; Nash, 1980). Landslides can also be visualized as disequilibrium features, a result of too-rapid perturbations to a more gradual slope retreat. Slope failure disrupts the previous profile of the wasting slope, inducing new, usually steeper gradients in the head region, and building a depositional mound at the toe.

In order to define morphologic changes with time, one must start with a detailed description of the fresh morphology of landslides. Rib and Liang (1978) have compiled in matrix form the key morphologic characteristics of 11 different types of landslides. Different morphologic regions of the slide are described separately for each type: parts surrounding the slide (crown, main scarp, flanks) are dealt with apart from the slide itself (head, body, foot, toe). Their detailed chart is the obvious point of departure from which to group or quantify morphologic changes with time. For this paper, those features which are common to many landslide types are described in the top row of Table 2.

Morphologic dating of landforms is an integral part of two geologic subdisciplines today, glacial geology, and tectonic geomorphology. Recent trends toward quantification of relative-dating (RD) parameters for glacial deposits

Table 2--- PRELIMINARY AGE CLASSIFICATION FOR LANDSLIDES

(for Bridger - Teton National Forest, Wyoming)

AGE CLASS	HEAD SCARP	LATERAL SCARP & DRAINAGE	INTERNAL MORPHOLOGY AND DRAINAGE	VEGETATION	TOE RELATIONS	ABSOLUTE AGE (ESTIMATED)
1. ACTIVE	Sharp, Unvegetated	Sharp, unvegetated, streams at edge	Undrained depressions, lakes, hummocky topography, angular internal blocks separated by unvegetated cracks	Absent or sparse on lateral and internal scarps; tilted ("jack-strawed") trees common	Forces axial-drainage to opposite valley side where active slides occur, dams drainage, covers modern flood plain, not modified by stream	Activity within historic time by definition[a] (Based on historic settlement around 1880 A.D.)[b] for Jackson Hole area, implies less than about 100 years old.)
2. INACTIVE Young	Sharp, partly vegetated	Sharp, partly vegetated, small tributaries to lateral streams	Undrained and drained depressions, ponds and marshes, hummocky topography, internal cracks vegetated	Younger than adjacent terrain or different type or density	Same as above, but toe may be modified by modern axial channel	100 - 5000 years[c]
3. INACTIVE Mature	Smooth Vegetated	Smooth, vegetated, tributaries up onto body of slide	No undrained depressions, but smooth, rolling topography, drainage network shows derangement	Same age as adjacent terrain, but maybe different type or density	Covers Pinedale terraces, but cut by modern flood plain meanders; stream not constricted but has widened flood-plain	5000 - 10,000 years[d]
4. INACTIVE Old	Dissected, Vegetated	Very vague lateral margins, no lateral drainage	No undrained depressions, normal dendritic channels cut into scar or deposit, drainage integrated	Same age, type and density as surrounding terrain	Truncated or overlapped by Pinedale or earlier (Bull Lake, pre-Bull Lake) moraines or terraces	Older than 10,000 years (often MUCH older)

FOOTNOTES:

a- DEFINITION OF ACTIVE LANDSLIDE: Active within historic time, based on: 1) documentary evidence, 2) eyewitness reports of movement, 3) displacement or disruption of man-made features, OR 4) possession of extremely fresh morphologic features similar to those found in slides with documented historic movement.

b- Based on a population of 64 people in Jackson Hole by 1889 (Hayden, 1956, p. 14.)

c- 5,000 year older limit tentively based on characteristics of the Devils Elbow rockfall deposit (Gros Ventre River; Sec. 6, T42N, R114W) dated at roughly 4120 ± 200 years B.P. (Bailey, 1971, p. 45-46)

d- Includes events immediately following the last major glaciation (Pinedale or equivalent); older limit becomes younger with increasing elevation.

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Bailey, R.G., 1971, Landslide Hazards Related to Land Use Planning in Teton National Forest, northwest Wyoming: U.S. Department of Agriculture, Forest Service, Intermountain Region, 131 pages

Hayden, E.W., 1956, History of Jackson Hole: Wyoming Geological Association, 11th Annual Field Conference, p. 8-19, Jackson Hole, Wyoming

have resulted in the identification of several morphologic parameters which change predictably with age (Burke and Birkeland, 1979). For example, moraines that begin as sharp-crested, angle-of-repose ridges gradually lower, flatten, and broaden with time. Bouldery ridges similar to moraines are formed by rockslides and rockfall avalanches, especially near the flanks and toe, resulting in features which when fresh somewhat resemble lateral moraines (e.g. Gros Ventre Slide, Voight, 1978). Slope angles can be either measured or estimated from airphotos, depending on scale and resolution; resulting angles can then be compared to those on nearby dated glacial deposits. Of course, angles could also be measured in the field.

Scarps at the head and flanks of landslides are often similar to fault scarps in unconsolidated material. The morphologic dating of fault scarps has been recently advanced by Wallace (1977), Bucknam and Anderson (1979), and Colman and Watson (1983). In the absence of reactivation, steep scarps in unconsolidated materials undergo slope decline and scarp broadening with age. The age of the scarp can be calculated from the relation between its height and maximum slope angle, if degradational constants (due to climate, aspect, vegetation, and lithology) are known. Even without a correction for differences in the above factors, the scarp-height versus slope-angle relationship could be used as a preliminary estimation of landslide scarp age in the western United States.

AGE CLASSIFICATION OF LANDSLIDES FOR INVENTORY MAPPING

Morphologic dating of landslides can usually only tell us about the time since the latest episode of movement. In the same manner that later glacial advances obliterate traces of earlier ones, renewed movement of a slide mass can destroy evidence of earlier movement and thereby "reset the clock". Exceptions to this situation arise when later movement is restricted to a smaller or different area than earlier movement. It is common for large inactive slides to include small active areas, either renewed spalling off the head scarp, or slumping due to undercutting of the toe by a stream (e.g. Downie Slide, Piteau et al, 1978). A variation on this situation occurs at the Gros Ventre rockslide, where the 1925 slide did not quite remove the entire unstable mass, and scars of older slides extend above the headscarp and beyond lateral scarps (Bailey, 1972; Voight, 1978).

ACTIVE LANDSLIDES

The first age distinction to be made in landslide inventory mapping is between those slides which have undergone historic movement and those that have not. In the proposed classification, any historic movement classifies a slide as "active." For planning purposes, any slide which has moved in recorded time (about 100 years in the western U.S.) should be considered as having potential for renewed movement. The more restrictive definitions previously listed for active slides on Table 1 are hard to apply in inventory mapping. For example, if one is mapping on aerial photographs which are ten years old, there are practical problems in determining if a slide is "currently moving" or has moved "within the last cycle of seasons". (Varnes, 1978).

Historic movement can be documented in a number of ways: by written reports, oral eyewitness accounts, or displacement of obviously man-made features. In sparsely populated areas some provision should be made for the fragmentary nature of records. One way to handle this is to consider a slide of unknown age to be historic if it has morphologic features similar to those of historic slides nearby. Although this assignment could be somewhat subjective, it should reflect the fact that "active" slides are automatically marked as potential troublemakers.

Historic landslides typically possess the fresh, unmodified morphologic features listed in compilations such as Rib and Liang's (1978). A diagram of a fresh, generalized landslide showing morphologic components is shown in Fig. 1a. The main scarp is fresh, often ragged, and shows the original irregularities of the break. Head scarps are unvegetated and steep. Internal blocks have sharp margins and are well defined. Pre-slide drainages are abruptly truncated, but are not yet rejuvenated upslope. There has been insufficient time for the development of large marginal drainage channels. Closed depressions, often containing ponds, are common on the slide surface. The slide toe may interfere with modern valley-bottom drainage, and cross-cuts everything except the presently active channel, which may cut a narrow, steep, bouldery slot through the toe where it impinges on the stream. Lakes formed upstream of slide-toe dams are usually good evidence of fairly recent movement. Other age-dependent characteristics of an idealized landslide are given in Table 2.

Inactive-Young Landslides

Landslides that have not moved within historic time will have more subdued features than active landslides. Fig. 1b shows how the modification of original topography due to erosion and deposition "softens" the harsh lines of the original slide. Scarps become smoother in plan view due to erosion of earlier protruberances, and simultaneously decrease in angle and begin to be vegetated. The drainage network begins to accomodate itself to the new topography, by extending marginal tributaries headward. Drainages truncated by scarps entrench upslope, while downslope beheaded drainages may be abandoned and begin to fill with locally derived sediment via sheetwash and eolian processes, However, the drainage network on the slide is still poorly integrated. The slide toe is trimmed back from lateral erosion by any existing streams; this in turn triggers debris slides and small slumps along the margin of the toe. Table 2 lists other details characterizing this stage of development.

Inactive-Mature Landslides

The mature landslide is in transition from a mass-movement dominated landform to a fluvial-dominated landform. Tributaries of the marginal drainages extend themselves into the slide mass and begin to drain the area of formerly chaotic topography. Ponds in closed depressions are filled with sediment, and then in turn slightly dissected as integrated drainage reaches them. Thick vegetation covers the scarps and slide scar, leaving only the subdued topo-

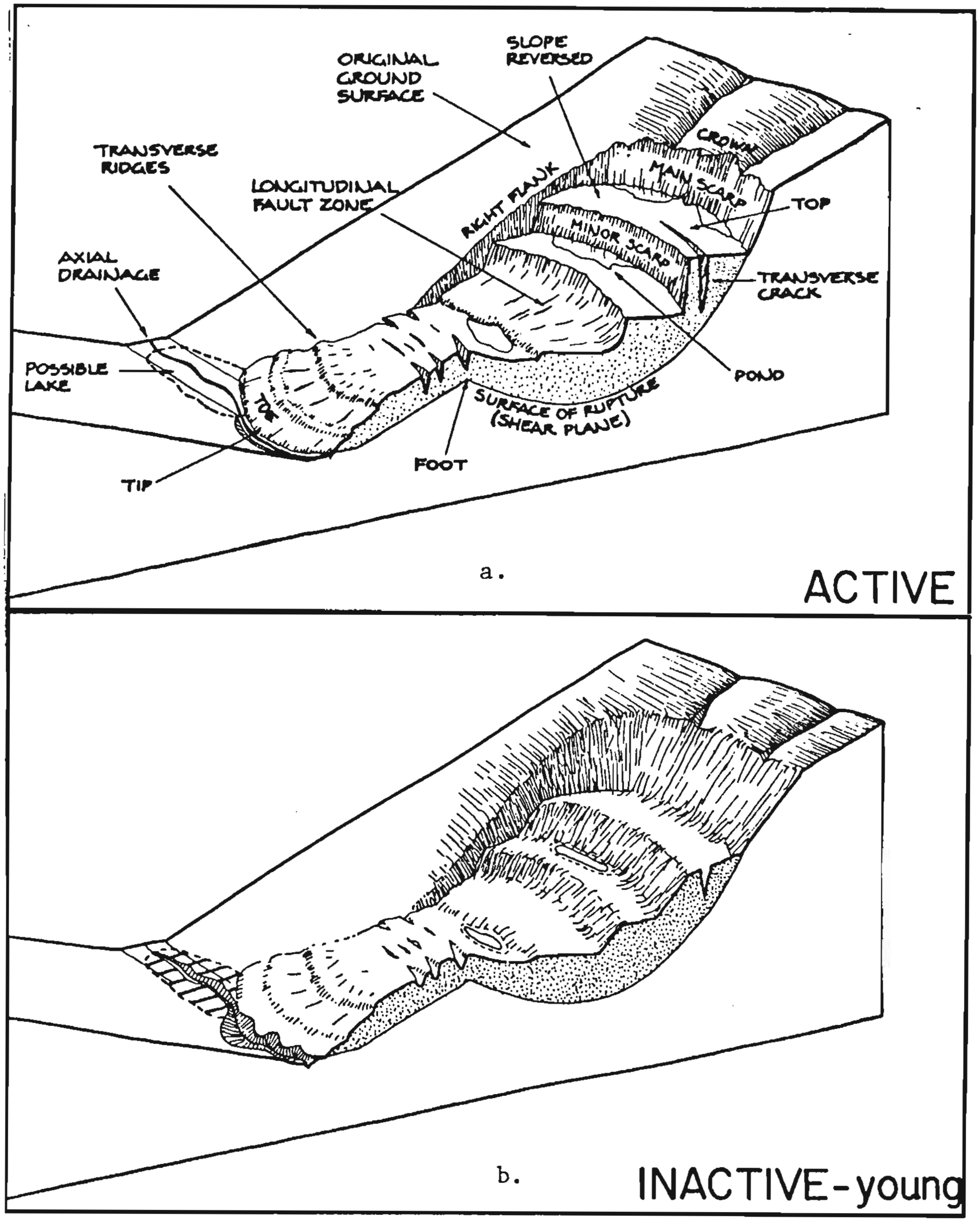

Fig. 1. Block diagrams of an idealized landslide showing morphologic changes with time. a- active slide, composed of sharply-defined components; b- inactive-mature slide, slopewash and shallow mass movements modify sharp edges, but drainage lines are not established.

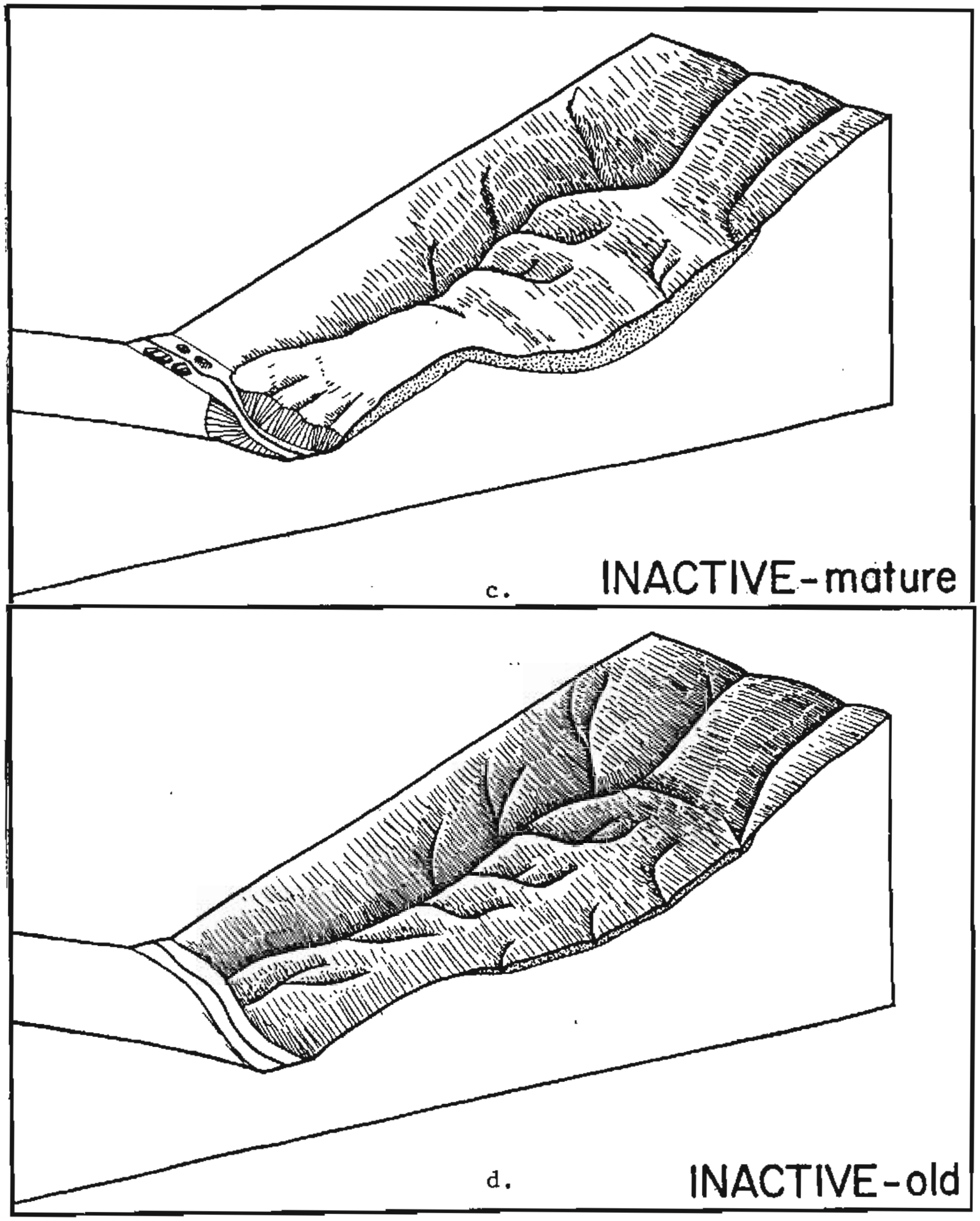

Fig. 1 (cont.); c - inactive-mature slide, drainage follows rifts and sags on the slide mass, internal blocks are slightly dissected, material is eroded from slide mass; d - inactive-old slide, slide mass is almost completely removed, drainage network shows weak structural control, valley drainage re-establishes its pre-slide profile.

graphic relief and arcuate shape of the headscarp to indicate the presence of a former slope failure (Table 2). Fig. 1c shows what a slide might look like in this stage.

In northwestern Wyoming, a large percentage of Inactive-mature landslides are associated with glacially oversteepened sides of U-shaped valleys. It appears that failure of these masses followed soon after deglaciation of the deep mountain valleys. Because deglaciation proceeded from lower to higher elevations at the close of the Pleistocene, most landslides triggered by ice retreat would presumably be somewhat older at lower altitudes than at high ones. However, the rapidity of alpine deglaciation deduced from radiocarbon chronologies elsewhere in the U.S. (Porter, 1980) suggests that perhaps only 2000 years was required for complete deglaciation of mountain valleys.

Inactive-Old Landslides

When performing photogeologic mapping of hilly terrain, occasionally a drainage basin will appear to be slightly anomalous. Some subtle difference exists between this basin and its neighbors. Perhaps the drainage divide at the head looks more arcuate than usual. The pattern of the tributaries in the basin may look anomalous without being deranged. Faint undulations of the ground surface under the tree cover may trend at an angle to the normal dendritic pattern. The stream valley at the mouth of a tributary basin may make a gentle but unmistakable swing to the opposite valley side. Individually, each perturbation could have several origins, but collectively, they all suggest an old, eroded landslide. In rugged terrain the landslide toe will probably have been eroded away by the incising valley axis channel. Alternatively, slide toes on aggrading valley floors may be partly or completely buried. The scarp area, perhaps developed on generally competent, but locally fractured rocks, may persist as a recognizable landform long after the landslide deposit is removed (Table 2 and Fig. 1d).

It is important to note that, although the erosional evidence of old-age landslides can still be identified on air photos after tens of thousands of years, geologic maps do not delineate the source area of landslides if they contain no mappable deposits. Thus, a geologic map showing landslide deposits is useful for locating slope failures of active and inactive-young ages, but is less useful for finding inactive-mature landslides, and may be totally inadequate to identify inactive-old landslides, if depositional evidence has been removed or obscured.

Multiple-Age Landslides

Larger landslides are commonly composed of several age zones, each with a different age of latest movement. Steep scarps created at the slide crown and toe often induce secondary small-scale slumping, while the body of the slide remains unaffected. Debris flows or earthflows that funnel through narrow necks before spreading out into wide lobes often display fresh cracks and scarps in the neck, while the terminal lobe itself shows no signs of movement. If scale allows, the different age zones of multiple-age slides should be delineated and labelled. One reason for this practice is that the active movement zone can migrate up- or downslope and manifest itself at a critical location several years later.

In some landslides morphology will include evidence of very recent movement together with features of much older movement. Conservative interpretation would require that such a landslide be classed in the category consistent with the freshest morphologic features. Thus, if a slide has subdued marginal scarps, partly filled ponds, and well-developed marginal drainages, but its toe dams a valley drainage, it should be classed as active regardless of other evidence.

FACTORS INFLUENCING MORPHOLOGY BESIDES AGE

Age is not the sole factor determining morphology. At least six other variables also control landslide morphology: 1) type of movement, 2) lithology of material, 3) slope steepness, 4) aspect, 5) climate, and 6) vegetation. The following is not meant to be a comprehensive review of these factors, but includes a few pertinent observations on how effects of these variables might be separated from effects of age.

The different types of landslides (falls, slides and flows) differ markedly in their original morphology. Some features particularly well developed in some types, such as closed depressions on slumps, are rare or absent on other types, such as rockslides. Alternatively, vegetation contrast can be high for rockslide deposits because vegetation commonly is destroyed during failure, whereas for slow-moving, thick earthflows, the vegetation is often rafted downslope while still growing. The detailed descriptions by Varnes (1978) and Rib and Liang (1978) of morphologic differences among landslide types should be firmly understood before attempting to apply age estimates to more than one slide type.

Coarse, bouldery rubble in a landslide deposit will resist revegetation and stream modification longer than will a deposit rich in silt of clay. Similarly, a landslide scarp which exposes a very resistant rock cliff would be expected to maintain its form longer than a steep head scarp in cohesive but unconsolidated colluvium or till.

The steepness and the aspect of the slope which failed also control the degradation rate of the slide. In the Teton National Forest, slides occurring on north-facing slopes are covered by vegetation faster, but often retain their bowl-shaped form longer than do similar slides on south-facing slopes. The contrasting soil moisture and mass-wasting regimes on opposing slopes speed up some degradation processes in relation to others. Aspect, vegetation, and climate are necessarily interrelated. Within any one area differences in morphology caused by climate are small because climate is nearly a constant. In areas of vastly different climate however, differences of morphologic preservation can be apparent. For example, the Blackhawk Slide in the arid Mojave

Desert of California (roughly 18,000 yr old; Johnson, 1978) has considerably fresher topography and sharper contacts than does the 4000 year-old Devil's Elvow Slide in montane Wyomong (Bailey, 1972).

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The adaptation of modern geomorphic descriptive methods to landslide age determination is still in its infancy, especially compared to applications in the fields of glacial geology and tectonic morphology. Although the key to using morphology to date landslides lies in predictable changes with time, the variety of different types of landslide movement presents us with a bewildering array of landform elements. Within any given area and for each major slide type, a relative-age hierarchy of slides can be constructed based on: 1) freshness of morphologic features, and 2) relations with other geomorphic features. The next logical step in landslide age research is to make detailed studies of a series of dated landslides of a single type to identify which changes and rates apply to what landslide types. Another potentially fruitful field of endeavor would be to determine if other non-morphologic relative-dating parameters, such as the measurements of surface clast weathering which have proved successful in deciphering late Pleistocene glacial chronologies, can be applied successfully to landslides. The author will be investigating this possibility for rockslides during the 1984 field season, using the parameters listed in Table 3.

TABLE 3
STANDARD RELATIVE-DATING (RD) PARAMETERS USED IN GLACIAL GEOLOGY[1]

1. Percentage of oxidized stones	8. Maximum lichen diameter
2. Percentage of pitted stones	9. Surface boulder frequency
3. Maximum pit depth	10. Boulder burial factor
4. Percentage of stones with weathered rinds	11. Moraine crest width
5. Maximum rind thickness	12. Maximum moraine slope angles, outer and inner
6. Average rind thickness	13. Soil profile development
7. Maximum percentage of lichen cover	14. Subsurface weathering of stones

[1]after McCalpin, 1983, Table 1.

A final need is the calibration of these somewhat broad age categories by absolute dating. Although the RD-methods referred to previously can be used (with caution) to estimate approximate ages, their accuracy at time scales of 20,000-30,000 years is low. For determining ages of discrete movement events on a single slide, or on a large percent of slides within a basin, accurate absolute dates are needed. Risk analysis for landslides, like that for earthquakes, should eventually incorporate some data on recurrence intervals. An accumulating body of observations (Bible and Palmquist, 1978) suggests that occurrence of landslides in time is not random, but may be triggered by episodic external processes, such as earthquakes or climatic change. Dating episodes of landslide movement with morphologic parameters can be done on any slide, while finding datable material in slides is difficult. For planning and engineering purposes, some reliable estimate is needed for age of each landslide mapped in an inventory survey. The proposed classification, while not the final word, may point the way towards obtaining the information needed on this crucial question.

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