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S. Marie Lookingbill
Central Junior High School

Malcolm K. Cleaveland
University of Arkansas, Fayetteville

Margaret J. Guccione
University of Arkansas, Fayetteville

BOTANICAL EVIDENCE FOR HOLOCENE MOVEMENT OF ROCK STREAMS IN ARKANSAS

S. MARIE LOOKINGBILL
Instructor
Central Junior High School
Springdale, AR 72764

MALCOLM K. CLEAVELAND
Research Associate
Tree-Ring Laboratory
Department of Geography
University of Arkansas
Fayetteville, AR 72701

MARGARET J. GUCCIONE
Assistant Professor
Department of Geology
University of Arkansas
Fayetteville, AR 72701

ABSTRACT

Botanical studies of rock streams on the western half of Rich Mountain and on the north slope of Mt. Magazine in Arkansas question the common presumption that such streams require periglacial conditions to form, and are now inactive relict features in this area. Trees along the margins of the streams examined show abundant evidence of trauma resulting from Late Holocene movement, in the form of bent and tilted stems. Cross sections of trees demonstrate marked eccentric growth associated with tilting and cambial trauma associated with corrasion by rocks. That this damage is not the result of excessive snow loading is indicated by the lack of such stressed trees away from the stream margins. Stressed growth and shortened lifespan of trees on the Rich Mountain rock stream margins is shown by the small diameter (less than 15 cm) of most, while older and larger trees are found on higher slopes away from the stream.

These rock streams are indicated to be moving, active features, not stabilized relicts of the Pleistocene. Further study would permit more testing of this hypothesis and the establishment of a chronology of movements in the last century.

INTRODUCTION

White (1981) defines a block stream as an elongate body of rocks extending farther downslope than across slope; occurring on mountainsides or in the heads of ravines; overlying solid or weathered rock, colluvium, or alluvium; and existing above or below treeline. In this report block streams are referred to as rock streams.

It is commonly assumed that periglacial mass-wasting processes produce rock streams (White, 1976), including those found in the Appalachians (Hupp, 1982), the St. Francois Mountains of southeastern Missouri (Peltier, 1950), and the Ouachita Mountains of west-central Arkansas and east-central Oklahoma (Stone and McFarland, 1979). The periglacial conditions of semipermanent snow fields and numerous freeze-thaw cycles causes rocks to loosen from the cliff faces. These blocks are transported downslope by creep, solifluction, gelifluction, or a combination of these processes. After emplacement, fine materials are removed by rain and snow meltwater. When conditions favorable to the formation and downslope movement of these rock streams no longer exist, they become stable, relict features, presumably of Pleistocene age.

Mass wasting has been proposed as the general process responsible for the formation of rock streams. Rapid mass wasting processes include slab failure, rock avalanche, and rockfall. Slab failures are the common form of weathering on steep walls in hard rock. The release of lateral confining pressures permits the opening of joints which cut across geological structures or bedding planes. The result is a mass of closely fitting masonry whose strength is entirely derived from friction between blocks (Selby, 1982). Rock avalanches result when well-jointed rocks lose internal cohesion. Rockfalls are confined to the removal of individual and superficial blocks from a cliff face. Rock avalanches and rockfalls are considered to be important processes in the formation of the rock streams on Mt. Magazine and Rich Mountain. Groundwater seepage, ice crystal formation, and ice wedging contribute to the formation of separated blocks by infiltration and expansion along bedding surfaces and vertical fractures. Eventually, the collapse of large sections of the cliff occurs and forms the rock streams (Vere, 1986).

Rock streams may creep downslope or they may surge. Surging is sudden movement or an increase in the rate of movement of rock streams. Substrate movement associated with surging may create noticeable and datable changes in growth patterns of woody vegetation (Shroder, 1978; 1980). In contrast to rapid movement, rock creep involves long-term, slow deformation which is imperceptible except to observations of long duration.

Many attempts to determine if slope movement is occurring and to date movement utilizing dendrochronology and other botanical methods have been made (LaMarche, 1968; Shroder, 1978, 1980; Hupp, 1983, 1984). Dendrochronology has been used to date rock avalanches (Butler *et al.*, 1986), fault movement (Page, 1970; LaMarche and Wallace, 1972) and volcanic activity (Smiley, 1958; LaMarche and Hirschboeck, 1984). Dendrochronology is superior to the radiocarbon technique for the exact dating of young geological events in part because dendrochronological dates do not have uncertainty (expressed as "plus or minus" error parameters) associated with them (Claque *et al.*, 1982).

Many different internal and external, structural and morphological changes occur in trees because of downslope movement. Mass movement events can cause permanent changes in external tree morphology such as inclination or tilting of stems, shearing stress on roots and stems, corrasion scars or bark removal, burial of stems, exposure of roots, inundation, and denudation or the production of bare ground (Shroder, 1978). Tilting of trees is the most common morphologic change on Mt. Magazine and Rich Mountain.

Immediate environmental change is reflected in internal structure and morphology, affecting annual growth rings of trees (Shroder, 1978, 1980; Hupp, 1984). Abrupt tilting of a tree results in subsequent rings that are wide on one side of the trunk, in contrast to the opposite side where the same rings are relatively narrow. When this pattern of eccentric rings appears after years of relatively concentric ring production, the date of the onset of the eccentric growth is usually within one year of the event that caused the tilting (Hupp, 1984).

This botanical investigation of rock streams on Mt. Magazine and Rich Mountain was undertaken to determine: 1) if these rock streams are static, relict Pleistocene periglacial features or, 2) if they have moved recently or are presently moving, and, if so, what is the rate of movement (steady or surging). This investigation included observations of tree morphology along rock-stream margins, examination of selected tree cross sections, and comparison with a local tree-ring chronology.

SITE DESCRIPTION

Mt. Magazine is located in the Arkoma foreland basin in west-central

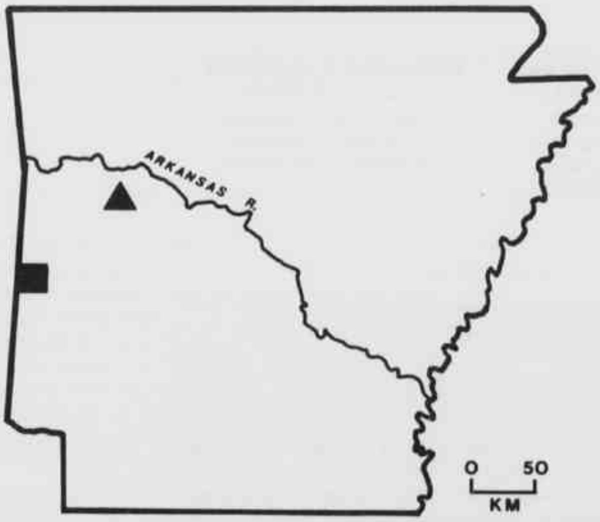

Figure 1. Map of Arkansas showing locations of rock streams studied. Triangle: Mt. Magazine; Rectangle: Rich Mountain.

Arkansas (Fig. 1). The caprock is Savanna Sandstone, a Pennsylvanian deltaic deposit. The moderately thick-bedded, gray sandstone is relatively resistant to weathering. A more or less continuous cliff up to 30 meters (m) high surrounds the uppermost slopes of the mountain (Vere, 1982). Underlying the Savanna Sandstone is the McAlester Formation, a unit that is less resistant to weathering and enables tree cover to develop on its slopes.

Below the cliff face and extending downslope for several hundred feet in some places, are numerous boulder-covered, vegetation-free surfaces (Fig. 2). These are rock streams. The largest rock stream occurs on the north side of Mt. Magazine (Vere, 1982) and is the study site.

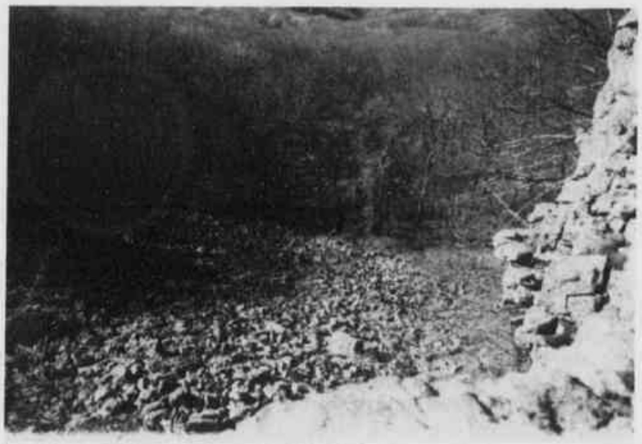

Figure 2. Looking downslope from the cliff at the head of the Mt. Magazine rock stream. A lower section of the rock stream is in the center background, separated from the upper section by a levee-like area.

The upper and most extensive portion of the rock stream is immediately below the cliff face. It is approximately 100 m long by 100 m wide and has an average slope of 27 degrees. The lower portion of the stream is more elongate and not as wide (approximately 230 m long and 15 to 30 m wide) as the upper portion (Vere, 1982). The slope decreases to between 2 and 14 degrees.

Rich Mountain and Black Fork Mountain are located along the Arkansas-Oklahoma border in the Ouachita Mountains (Fig. 1). Both mountains are elongate, east-west trending ridges composed of the Pennsylvanian Jackfork and Stanley Formations. The Jackfork Formation includes beds of resistant, thickly-bedded, gray sandstone and easily weathered shale. The steep north-facing slope of Rich Mountain and south-facing slope of Black Fork Mountain are composed of a cliff of Jackfork Sandstone at the mountain crest underlain by the Stanley Shale, an easily weathered unit. Elongate rock streams occur beneath these cliff faces or in ravines farther down the mountain slopes.

The rock stream examined here occurs in a ravine part way down the mountain on the north-facing slope of Rich Mountain, along Oklahoma Highway 1 (Fig. 3). As seen at Mt. Magazine, forest vegetation is developed on a boulder-rich substrate on either side and above and below the rock stream. Beyond this area, normal forest vegetation is developed on a relatively boulder-free substrate.

Figure 3. Looking upslope from the toe of the Rich Mountain rock stream.

Unlike Mt. Magazine, however, normal forest vegetation is developed on a boulder-rich substrate from above the rock stream to the crest of the mountain. This vegetation includes all age classes of trees and some understory species. The block substrate has accumulated a sufficient amount of interstitial, fine-grained material to support tree growth. Also in contrast to Mt. Magazine, a cliff face is not present at the head of the ravine. However, small outcrops and abundant rubble does occur parallel to the slope near the crest of Rich Mountain, indicating a resistant bed of sandstone is present. This unit is the presumed source of the rock stream. Lobate features with lateral and terminal levees were observed in the ravine above the rock stream and may indicate that movement has occurred as debris flow (Selby, 1982).

METHODS

Field work consisted of noting the morphology of trees adjacent to the rock streams and locating trees that showed stress, such as leaning or bending. Three samples were taken for laboratory analysis. The trees selected were bent at least twice and were not over 10 centimeters (cm) in diameter. One sample was taken on Mt. Magazine and the other two samples were taken on Rich Mountain. Finally, tree diameters at 1.6 m height were measured at three sites adjacent to the rock stream on Rich Mountain. Each measurement was taken within a plot having approximately a 6.0 m radius.

Laboratory work consisted of sample preparation, species identification, and tree-ring analysis. The stem cross sections were sanded to a smooth finish with consecutively finer grades of sandpaper, starting at 120 grit and finishing with 400 grit. The genus and species, where possible, were identified by wood anatomy (Panshin and de Zeeuw, 1970) and bud and bark morphology (Harlow *et al.,* 1979). The tree rings were examined with a binocular microscope at 7 to 30X magnification in the Tree-Ring Laboratory of the Geography Department, University of Arkansas, Fayetteville. Ring boundaries were marked; rings were counted; and ring widths were measured using a computerized tree-ring measurement system (Robinson and Evans, 1980). This data was compared to the standard tree-ring index chronology for white oak *(Quercus alba)* from Black Fork Mountain, Arkansas (Stahle *et al.,* 1985) for crossdating purposes (Stokes and Smiley, 1968).

RESULTS

Tilting of trees is the most common morphologic change seen in trees on Mt. Magazine and Rich Mountain. Tilting is recorded in tree growth by eccentric ring development, by the production of anatomically distinct reaction wood on the upper side of hardwoods, and by bent trunks (Fig. 4) as the tree subsequently grows upright again (Shroder, 1978). Single abrupt inclination events generally produce easily dated changes in ring growth. Gradual or long-term multiple inclinations produce compound trunk curvature as well as complex reaction wood which may be very difficult to date (Shroder, 1978).

Figure 4. A bent tree (foreground) growing near the bottom of the upper section of the Mt. Magazine rock stream.

A bent holly tree (*Ilex* sp.) was sampled on the western margin of the upper portion of the Mt. Magazine rock stream. The cross section of the sample has concentric rings for the first two years, followed by very eccentric rings (Fig. 5). This could be caused by the tilt evident near the base of the trunk. The eccentric growth occurs along at least

Figure 5. Cross section of holly tree sampled at Mt. Magazine. Note highly eccentric growth along several axes, indicating several episodes of tilting in different directions. The wood belongs to the diffuse-porous group. Each division of the scale is 1.0 cm.

two different axes, indicating that the tree was tilted in at least two directions at different times. The rings become very eccentric and very difficult to distinguish in the outer five rings of tree growth. This might be attributed to competition from surrounding trees or trauma affecting the root system. Several abrupt reductions in growth (Fig. 6) suggest that other traumas occurred and one may be recorded by the second bend in the tree.

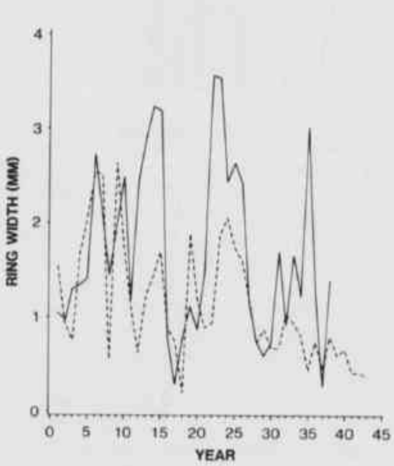

Figure 6. Radial measurements of the holly sample from Mt. Magazine along two lines marked in Fig. 5. Some of the outer rings are missing on one radius.

The cross section of black locust *(Robinia pseudoacacia)* collected at site D at the toe of the rock stream on Rich Mountain has concentric rings the first two years, followed by eccentric rings (Fig. 7). This change in growth, as well as a bend near the base of the tree, may have been caused by tilting. The cambium has died at one point on the radius (Fig. 7), evidence of corrasion or impact injury at that point. As a possible consequence of this trauma, ring 13 and subsequent rings (Fig. 8) are very small and discontinuous around the circumference of the stem.

Figure 7. Cross section of the black locust sampled at site C on Rich Mountain. This tree has ring-porous wood. Note the cambial wound (arrow) indicating direct trauma to the tree severe enough to destroy the cambium at that point. Each division on the scale is 1.0 cm.

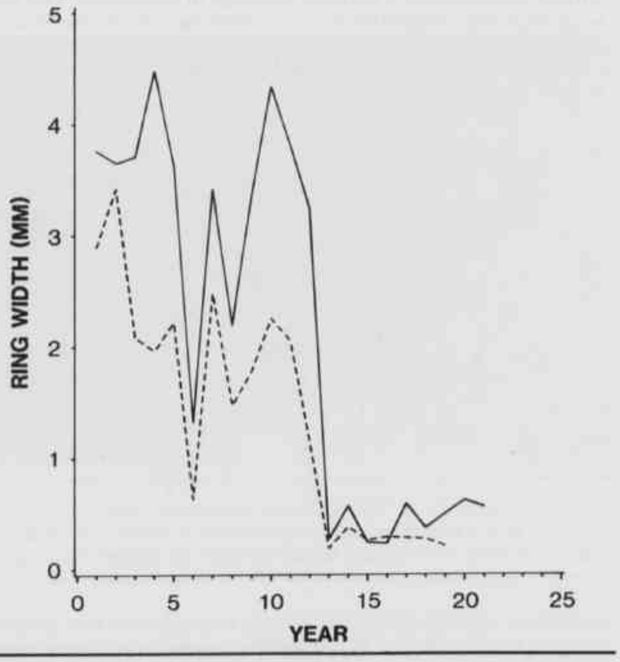

Figure 8. Radial measurements of the black locust sample from Rich Mountain. The abrupt reduction in growth at ring 13 may reflect the cambial injury seen on the cross section (Fig. 7). Some of the outer rings are missing from one radius.

The cross section of the persimmon tree *(Diospyros virginiana)* collected at site B on the western edge of the Rich Mountain rock stream formed concentric rings the first seven years, followed by somewhat eccentric rings (Fig. 9). Ring 8 has a dark layer that could be evidence of trauma. An abnormally abrupt reduction in growth after the fifth ring (Fig. 10) may be associated with tilting or injury. This trauma may also be recorded as a bend near the base of the tree that is the result of tilting. The last rings were very difficult to distinguish because growth was extremely slow, possibly a sign of injury.

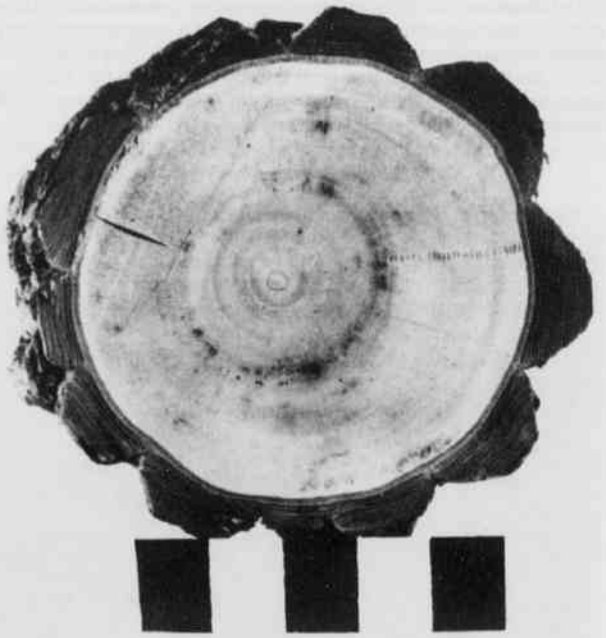

Figure 9. Cross section of the persimmon sampled at site B. This tree has semi-ring-porous wood. Each division of the scale is 1.0 cm.

Tilted trees are common on the vegetated, boulder-rich margins of the rock streams of both Mt. Magazine and Rich Mountain. Most of the trees on Mt. Magazine are leaning or bent, some several times. One tree, noted but not sampled, had eight bends. These bends are evidence of catastrophic tilting and subsequent renewed vertical growth. It is possible that the pervasive malformation could result from snow and frost damage. However, drastically malformed trees appear to occur more frequently in the vicinity of the rock streams, an argument for downslope movement of these materials.

In contrast to Mt. Magazine, a large portion of the vegetated, boulder-rich surface above the rock stream on Rich Mountain supports normal forest vegetation. It remains unclear why some portions of rock streams accumulate deposits of fine-grained materials adequate to support vegetation. Boulder size and age of the deposit may be two contributing factors. The forest on Rich Mountain consists of a wide range of stem sizes and ages, while Mt. Magazine appears to have only smaller and/or younger trees. Some of the oak trees on Rich Mountain resemble the oaks sampled on Black Fork Mountain that attain ages of 300 years or more (Stahle *et al.,* 1985). All age classes, including the oldest,

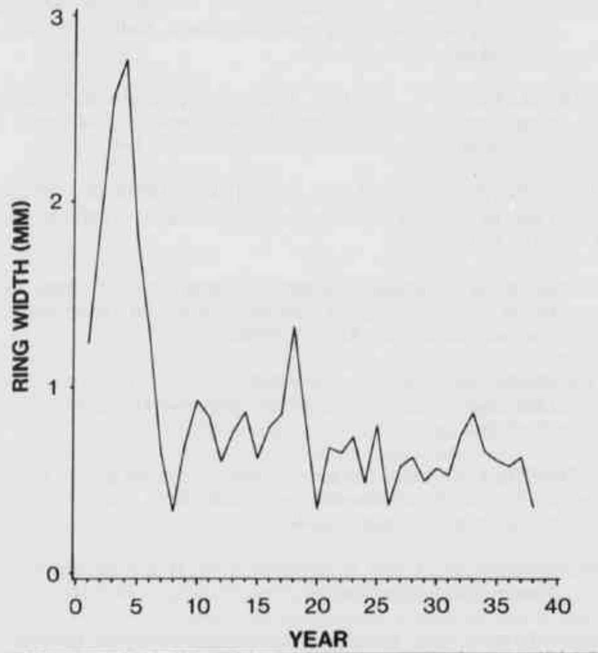

Figure 10. Radial measurement of the persimmon sample (Fig. 9) from Rich Mountain.

Figure 11. Several of the bent trees growing in the area above the Rich Mountain rock stream.

exhibit external morphological characteristics (Fig. 11) associated with an unstable substrate, such as abrupt bends in their stems (Shroder, 1978, 1980).

Quantitative measurements of tree diameter at three sites on the lateral margins of the lowest part of the Rich Mountain rock stream demonstrate a dominance of smaller trees (Table 1) with a greater abun-

Percent of Trees in Diameter Classes

Site	Diameter Classes (Cm) 2-8	9-15	16-25	26-33	34-40	41-60	No. Trees Measured
B	33	17	25	8	17	0	12
C	34	28	14	10	7	7	29
D	55	41	0	4	0	0	22

Table 1. Frequency of diameter classes of trees at three sites on the margin of the Rich Mountain rock stream. The classes were adjusted from even widths on the basis of apparent natural break points in the distribution.

dance of small trees near the toe of the rock stream at Site D (Fig. 12). Somewhat larger trees occur at sites B and C (about 20 m west of site B), higher on the lateral margins of the rock stream than site D. This suggests that the site at the toe of the rock stream is exposed to more

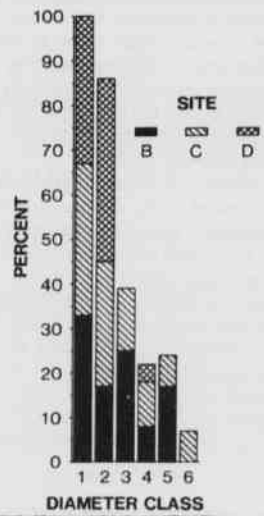

Figure 12. Graph of the trees in different diameter classes at sites B, C, and D. The classes are as shown in Table 1.

stressful conditions, or the trees are younger, while sites higher on the lateral margins of the rock stream are subject to less growth stress, or those trees attain greater ages.

Trees sampled on Rich Mountain in this study were compared to a white oak *(Quercus alba)* tree-ring chronology compiled by Stahle *et al.* (1985) from trees on nearby Black Fork Mountain, Arkansas. Because the trees examined in this study are young, and show highly variable growth patterns that seem to be influenced more by site disturbance than by climate, crossdating, *i.e.,* the matching of climatically controlled growth patterns (Stokes and Smiley, 1968), is extremely difficult. In addition, growth of the outer rings in all three samples is so suppressed that there are missing rings, rendering any one-to-one match impossible.

CONCLUSIONS

Rock streams exist on some mountains in Arkansas and Oklahoma where a relatively resistant, massive sandstone unit forms a cliff face above a less resistant shale unit. These rock streams are elongate bodies of coarse sandstone blocks commonly oriented approximately parallel to the slope. These blocks are derived from the cliff of resistant sandstone by mass wasting. The rock streams are similar to active features in alpine areas (White, 1976), and therefore have been considered to be relict features formed in a periglacial regime during the Pleistocene (Stone and McFarland, 1979).

There is botanical evidence for movement of the rock streams in approximately the past century. The central portion of the rock streams does not support vegetation because insufficient fine-grained material has accumulated. The botanical evidence is collected from the margins where vegetation is present. Tree growth in this area may also result from less frequent and violent mass movement compared to the central portion of the rock stream.

The evidence for rock stream movement during the life span of a tree includes external tree morphology, eccentric annual ring formation, and corrasion of the bark and cambium, resulting in abnormal ring formation or cambial death. Tree morphology on Mt. Magazine suggests that slope materials along the rock stream margins at this site are not stable and movement downslope occurs catastrophically or in surges. Many trees have multiple bends and a large number of trees are affected, although most do not attain a diameter greater than 15 cm. In contrast, the upper margin of the Rich Mountain rock stream has many mature trees. The presence of fine-grained materials upslope of the rock stream may facilitate movement as debris flows. Many of the trees above and along the lateral margins of the rock stream show morphologic evidence of movement. Therefore, slope materials at this site have moved relatively recently.

Cross sections of selected bent trees at both sites support the hypothesis of unstable slopes. All three samples examined have eccentric tree rings. These result from tilting, probably caused by active slope movement. One sample also exibits evidence of mechanical damage to the stem, probably the result of direct damage to the stem and/or root system of the tree by moving rocks.

This study demonstrates that botanical evidence can substantiate, and potentially date, movement along the margins of rock streams. These data support the hypothesis that Holocene movement occurs and that the rock streams are not stable relict features. Further study and many more samples (Butler *et al.*, 1987) are needed to accurately date the downslope movement, to determine if movement within and among the rock streams are synchronous or are isolated and sporadic events, and to establish the recurrence interval. Trees at the margins of the rock streams should be compared to trees growing in the areas between rock streams where the predominant mass-movement mechanism is creep. These more stable trees can be used to construct a tree-ring chronology and accurately date movements on the adjacent rock streams.

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