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7. Debris Avalanches and the Origin of First-Order Streams

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Landslides in general and debris avalanches in particular are of concern to engineers who encounter them in the course of highway construction (Whitney et al. 1971). They are also of interest to botanists, because they offer an opportunity for the study of plant succession on naturally denuded slopes (Flaccus 1959). Catastrophic natural processes are becoming of greater concern as population pressures force humans to live on less and less desirable, steeply sloping land. Geologists have been concerned with avalanches at least since 1826, when an avalanche was reported in the White Mountains of New Hampshire. Lyell visited the site in 1845 and commented that the moving rock mass had removed the glacial striae from the bare granite surface testifying to the erosive power of the moving avalanche (Lyell 1875).

The literature on mass wasting is abundant in many parts of the world, especially in those regions of recent orogenic activity. In older mountain chains, with warm humid climates underlain by metamorphic rocks such as the southeastern Blue Ridge Mountains, data are especially sparse. Sharpe (1938) described avalanches as leaving long narrow tracks on steep mountain slopes. He also emphasized humid climates as a factor in their formation. Avalanches have regional characteristics which include climate as well as geology and topography (Krynene and Judd 1957). According to this concept slides within a geomorphic region possess similar characteristics. Data from the numerous (186) debris avalanches produced in Virginia by Hurricane Camille showed that the deluge, 28 inches of rain in 8 hr, was a factor (Williams and Guy 1973). They also concluded that debris avalanches follow preexisting depressions in hillsides generally steeper than 35°. Rock type does not appear to be a definitive factor in avalanche formation, although shales are probably more prone to slide than other rocks (Vo 1978). Chemical weathering and structural features are significant in some slides, slides are common in areas of rapid mountain growth where chemical weatherin minimal (Voight 1978). In the southeast, chemical weathering is very prominent is a factor in slide development. Slopes most likely to produce rock avalanches du earthquakes are: steeper than 25°, higher than 150 m, undercut by active streams, c posed of intensely fractured rock, and at least one other factor such as: faults, bedc and foliation dipping down the slope, and weathering (Keefer 1984). Geologic st tures are frequently invoked as factors in avalanche formation and control. Th factors include jointing, bedding, faulting, and cleavage. They are usually part of descriptive data (Inners and Wilshusen 1983). Factors in the development of joint granite include topography, residual tectonic strain, and dilation. The unambigu assignment of any joint set to a single cause is not possible (Chapman 1958). A str correlation between jointing and folding is evident in the Inner Piedmont (Grant 19

In the Grandfather Mountain area of western North Carolina, circular pattern large size occur. They are related to joints which are classified as either tectoni exfoliation (dilation). Most tectonic joints match structural patterns inherited fro period of deformation (Hack 1966). The release of high confining pressure by rem of overlying rock is the most important cause of sheet jointing (dilation jointing granite (Hopson 1958). These views are adopted in this study, of which the m considerations are the relation between jointing and first order streams and betw dilation joints, tectonic joints, chemical weathering, and debris avalanches.

The Study Area

The work was done in the area around the Coweeta Hydrologic Laboratory (Fig 7.1). The geologic mapping was done for both the laboratory area and the Pren Quadrangle (Hatcher 1980). The geomorphology is typical of the Blue Ridge Mc tains. Locally, it is characterized by narrow sharp ridge tops flanked on either side steep slopes (30° to 45°). These are interspersed by somewhat rounded ridges and g tler slopes at lower elevations. The valleys of the upper slopes are steeper and shaped. They may contain large amounts of coarse rock debris, but little alluvi Broad valleys at lower elevations are flanked by moderately steep slopes and h almost flat gently sloping bottoms filled with alluvium. For the laboratory area maximum elevation is on Albert Mountain (1592 m). The minimum is near the c fluence of Ball Creek and Shope Fork (675 m). The total relief is 914 m.

The soil cover on the mountains varies greatly in thickness and development. steeper valley walls are bare rock or mantled with a thin creeping soil. The soil app to sustain its continuity by being laced together by interlocking plant roots. This co tion creates a ruglike integrity for the soil mass. These soils are not necessa residual. They may overlie rock or saprolite from which they are not derived. In sc areas, especially steep ones, bare rock with limited minor plant growth is exposed. the more rounded lower ridges, the more gently (<30°) sloping valley walls ma covered with residual soils. That is, the rock, saprock, saprolite soil sequence is c plete and apparently undisturbed. These observations are supported by the occurre

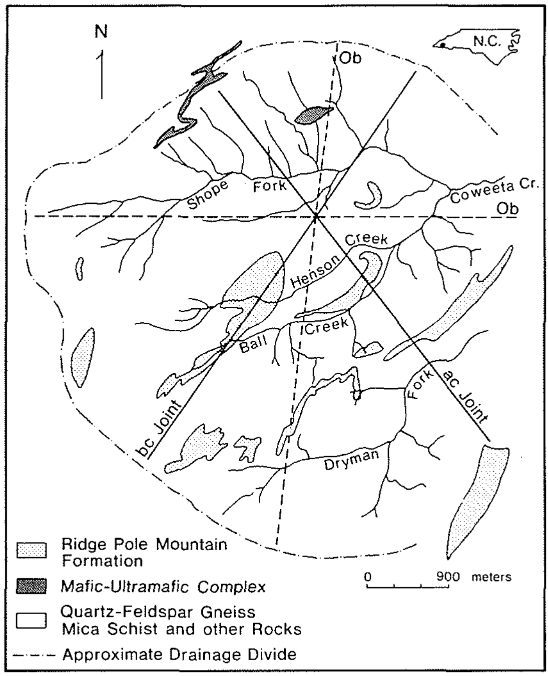


Figure 7.1. The major drainage system, the trends of two selected geologic formations (Hatcher 1980), and the directions of the tectonic joint maxima. The map center is approximately 35° 03′N by 83° 27′W.

of both residual (underlain by saprolite) and transported (creep) soils in Rabun County, Georgia, which borders Macon County on the south (Carson and Green 1977).

Alluvium in the lower valley bottoms is composed of very coarse sand and granules but particle sizes may range upward to boulders which are commonly 30 cm to 1 m in maximum dimension and much larger ones occur sparsely. Small quantities of clay minerals occur in all stream sediments.

Avalanche material includes all particle sizes from clay to boulders, but is strongly skewed towards the larger particles. It is thought that the particle sizes as well as the water content of a moving avalanche is different from the final deposit. Mudflows occur occasionally in the high rainfall areas of the southern Blue Ridge Mountains (Hursh 1941). These mudflows carry large rock fragments and are the same as debris avalanches.

The underlying parent rock strata are late Precambrian to lower Paleozoic metasediments which have been intruded in places by late Paleozoic plutonic igneous rocks, mainly granites. The most common rock type is a micaceous quartzofeldspathic gneiss. The most common minerals are quartz, oligoclase, biotite, muscovite, and potash feldspar. Sillimanite, kyanite, staurolite, and garnet are less common but important indicators of metamorphic grade. These rocks have been recrystallized by regional metamorphism (Hatcher 1980). Deformation at elevated temperatures amd pressures tends to homogenize the fabric and to a limited extent decrease the geomorphic importance of old planar structures such as bedding. Several episodes of folding have occurred, but only the last appears to be of geomorphic importance. These folds trend

roughly N38E–S38W (Figures 7.1 and 7.4) and are probably Alleghenian. Fu
geologic information is given by Hatcher in this volume (Chapter 5).

The Blue Ridge Mountains in the Coweeta area are steep. It is doubtful that declivities could have survived 300 million years of mass wasting without some ver movement. Data from Meade (1971) indicates on his map for crustal moveme the southeastern United States, vertical movement of between 3 mm and 4 mm per in the Coweeta area. Schaeffer et al. (1979) show active stresses are still prese the northwestern South Carolina Piedmont. Bandy and Marincovich (1973) poin that uplift near Los Angeles has been irregular (178 m in the past 36,000 years) that there has been little or no uplift in the last 50 years. Bollinger (1973) indi that minor seismic activity has been observed since 1794 in western North Caro Thus, it is logical that modern landforms are the product of Holocene climate inte ing with slow vertical uplift, but any indication of rate based on short term data doubtful value.

The annual precipitation and average temperature at Coweeta are adequa produce a well developed weathering profile, soil and saprolite (Chapter 3). How it is not as well developed as the warmer but somewhat drier Piedmont.

Methods

General rock, soil, and saprolite observations were made at stream and road cuts. major source of data are surface exposures and appropriate core samples. Joints, h lines, and foliations were measured with a Brunton compass. Thalweg vectors, plu and bearing were measured, from the 1:7200 scale map of the Coweeta Hydrol Laboratory (1972), along portions of first order streams which are straight for dista greater than 60 m. The restriction of the vectors to straight portions of str

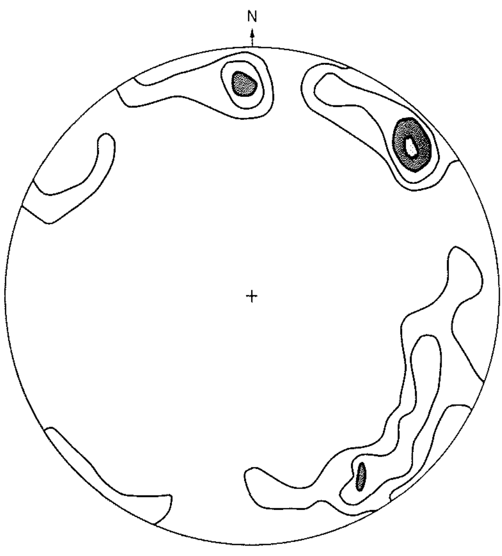
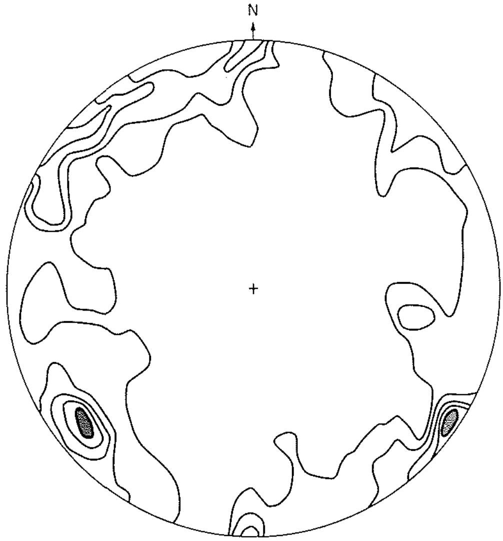


Figure 7.2. The bearing and plunge thalweg vectors measured from st segments of first order streams. Con 2, 4, 6, 8% per 1%.

Figure 7.3. Equal area distribution of 198 tectonic joint poles. Contours 1, 2, 3, 4, 6, 8, 10% per 1% net area.



eliminates irregularities introduced after the formation of a structurally controlled channel. The thalweg vectors are shown on an equal area projection in Figure 7.2. Joint distributions are shown on an equal area projection in Figure 7.3. The hinge lines are shown in equal area projection in Figure 7.4. The data contain 16 lines from the present work and 25 from Hatcher (1980). All structural data are taken as available and are somewhat irregular but widespread in their areal distribution.

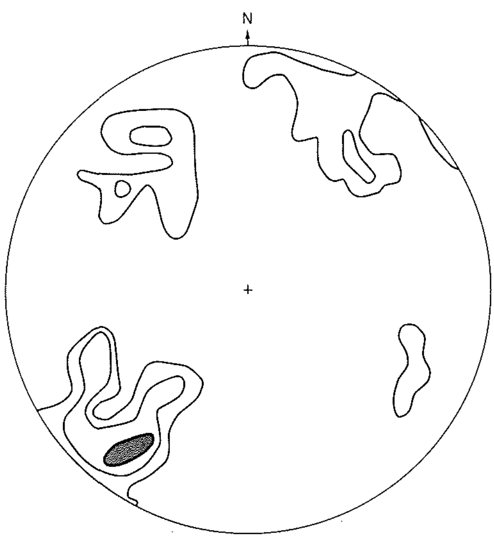


Figure 7.4. Bearing and plunge of 41 hinge lines. Contours 2.5, 5.0, 7.5% per 1% of net area.

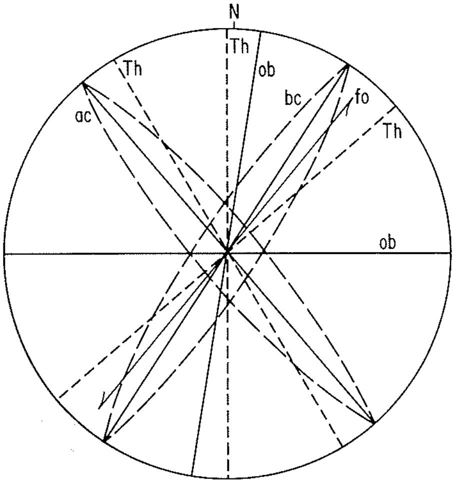


Figure 7.5. Generalized spatial relation between hinge-lines (*Fa*), tectonic joints (*bc*, and *ob*) and thalweg vectors (*Th*). Ec area projection.

Results

There are two, possibly three, fold trends shown in Figure 7.4. The strongest is appro mately N38E–S38W. A similar trend is evident in the geologic units (Figure 7.1). NE trend is taken as the major fold direction and the jointing is described on this ba The joints are resolved into four major sets: an *ac* set approximately normal to the f axis, a *bc* set approximately parallel to the fold axis, and two oblique sets approximat North–South and East–West (Figure 7.3). It is the correlation of jointing and fold which makes it probable that the joints are tectonic. These joint attitudes are simila the Schaeffer et al. (1979) account of jointing in the South Carolina Blue Ridge.

A comparison of the straight streams containing the thalweg vectors with the tecto joints (Figures 7.2 and 7.3) shows a close similarity in orientation. They are subpara to three of the four joint sets. The N90E oblique set is an impossible direction streams since it cuts across the hillsides. The relation between tectonic joints, thal vectors, and fold trends is summarized in Figure 7.5.

Dilation joints are subparallel to topography. Their dips may vary up to 90°. Most in the 30° to 50° range. They are probably formed as the result of elimination of con ing pressure by erosion of large amounts of overlying rock. They are much younger t the tectonic joints. Because of this dilation pressure, opening may take advantage of t tonic joints or foliation surfaces when they are appropriately oriented with respec topography, thus substituting for dilation joints. When occurring independently, d tion joints are gently curved, producing lenticular cross sections. The major surfi function of these two kinds of joints is to admit, store and provide for circulatior ground water. Ground water is responsible for chemical weathering, feeding sprir and is a factor in avalanche formation (Figure 7.6).

An example of a recent avalanche is shown north of Ball Creek about 0.2 miles sou west of the Laboratory Administration Building (Figure 7.6). A water bearing joint identified by drilling successive bore holes across the head of the chute. All ho

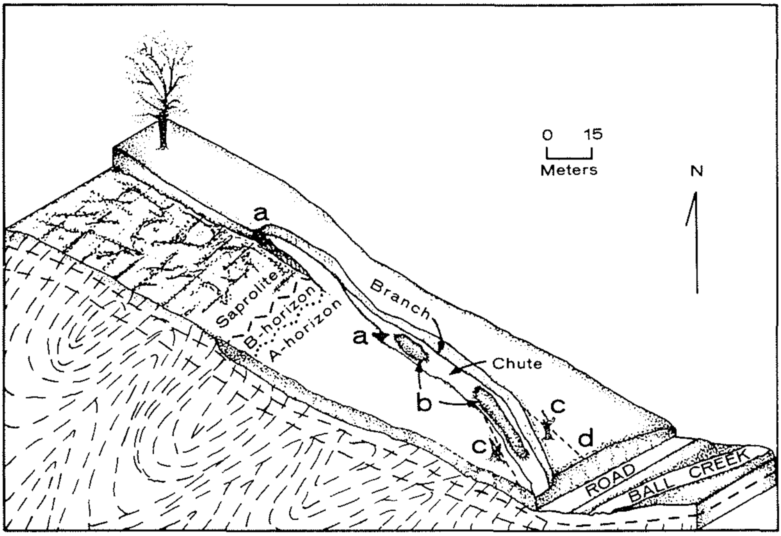


Figure 7.6. Coweeta debris avalanche map and section. The chute encloses remnants of the avalanche (b). Rock, thin saprolite and soil are shown. A small branch runs down the east side of the chute. Foliation, compositional layering, and four steep dipping tectonic joint sets and topographically subparallel dilation joints are indicated. Stippling along joints indicates the presence of water and weathering. The scarred trees (c) show that the avalanche upper surface was raised above general surface level during the movement period. The approximate width of the moving body is shown by dashed lines (d). The breakaway point is indicated at (a). The curvature in the lower part of the chute is probably caused by gravity.

stopped in rock at approximately 25 cm depth, except an aligned section which is water bearing. Here bore holes went down 1 m before striking rock. These deep holes have a bearing of N48W which is within the *ac* joint set. Along the whole length of the chute, except where avalanche debris remains, either bare rock is exposed or a thin, approximately 25 cm thick soil layer occurs. On either side of the chute drilling shows soil depths ranging from 1 to 1.5 m. Joint directions on rock outcrops are consistent with the data shown on the joint diagram (Figure 7.3). The exposed dilation joint surface is independent of the foliation which dips into the hillside. Evidence that the avalanche was a water inflated mass of rock, mud, and plant debris includes the scars on the upslope sides of surviving trees near the edges of the chute. The height of the scars, if projected across the chute, indicate that the avalanche was roughly lenticular in cross section, about 3 m thick and about 15 m wide during the time it was in motion. A small amount of the avalanche material still remains in the chute (Figure 7.6).

The contour plot (Figure 7.7) shows that most thalwegs, all of which are water bearing, plunge between 12° and 15°. This may have an effect on the permanence of avalanche generated streams, since at the time of formation they have chutes plunging about 30°. This situation may limit the groundwater reserve for sustained flow.

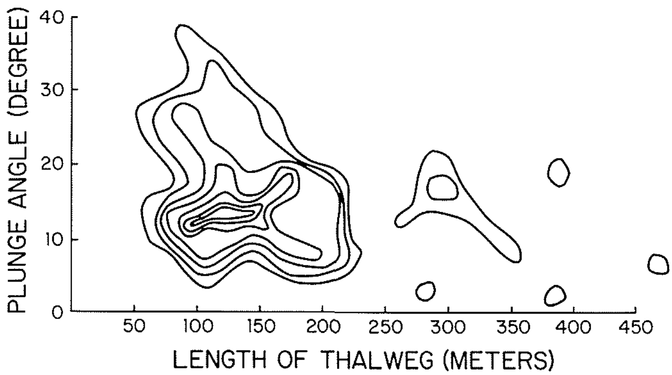


Figure 7.7. Contour diagram showing lengths and plunges of thalweg vectors. Contour inte
1%/cm² maximum 8%.

Conclusions

Debris avalanches and underlying joint systems are responsible for some first o streams. Other mechanisms exist for both phenomena. The sequence for developn of an avalanche associated with first order streams is as follows. A small depressio initiated by the subsoil intersection of two lenticular dilation joints with a downsl striking tectonic joint. Such a configuration could easily occur beneath a small val The depression accumulates ground water. Chemical weathering proceeds faster in depression enhancing its water capacity. This process can continue indefinitely o interrupted by a violent storm. The latter situation is discussed by Eschner and Pa (1982) who report a storm in May 1976 in the Coweeta area. Their data show 25 of gradually increasing rainfall which peaked sharply at about 18 to 20 cm per h This peak coincided with a debris avalanche. The avalanche is initiated by hydra pressure fed through the water saturated subsoil joint sysem. At the storm peak, p sure is strong enough to break the adhesion between the rock and the water satur soil and saprolite. The water inflated mass of rock and soil slides quickly down l leaving a chute as evidence of its passage. The chute is the locus of a new first o stream which needs only a sustained supply of water to develop into a steep-wa mountain valley.

In summary, the major subsurface water controls are soil-rock, saprolite-rock in faces, dilation, and subvertical tectonic joints. Metamorphism tends to promote development of dilation jointing independent of foliation by reducing the anisotrop the rock fabric. Thalweg vector plots support the relation between first order stre and joints. The optimum place for a new first order stream to form is on slopes of al 30° which are covered with thin soil and underlain by well jointed sap-rock.