CHAPTER FIVE

Surficial Map Criteria for Sandstone Landscapes of the Central Appalachians: Linkage of Landform, Material and Process

ABSTRACT

A surficial mapping protocol was developed for the unglaciated, humid-mountainous region of the central Appalachians. The technique emphasizes the link between landforms, materials, and processes in a landscape dominated by hillslopes, mass wasting, and fluvial erosion.

Three types of surficial map criteria are recognized. These include: Type I - polygonal map features associated with landforms and surficial deposits; Type II - discrete surface features not associated with surficial deposits; and Type III - observational features associated with data collection and field mapping. Type I units encompass landforms and deposits that result from *in-situ* weathering, mass wasting, fluvial processes, slope failure, and periglacial activity. Type II units include surface features associated with karst processes, slope failure, surface hydrology, and anthropogenic activity. Type III features include reference points, test pits, and soil borings used for data collection. Type I mapping criteria employ a four-fold scheme in which units are delineated on the basis of age, origin (process), landform, and material (texture). Type II and III criteria are mapped as two-dimensional surface features without reference to material or age.

Large-scale landform units in the central Appalachians are classified into hillslope and valley-bottom features. Hillslope landforms are subdivided into ridges, side slopes, hollows, and noses. Mappable hillslope variations include boulder streams, boulder fields, talus slopes, patterned ground, rock-block slides, debris-slide scars, and debris-flow tracks. Valley-bottoms are subdivided into channels, floodplains, terraces, fans, and aprons. Type II karst features include cave openings, sinks, solution pinnacles, blind valleys, swallows, and karst springs.

Colluvial diamicton is subdivided into side-slope facies, nose facies, and hollow facies. Hillslope hollows represent a geomorphically significant element and special consideration is warranted. Channel gravel is typically clast supported, moderately sorted, and imbricated due to deposition by turbulent streamflow. Fans in the central Appalachians are the products of a combination of debris flow, hyperconcentrated flow, and normal streamflow. Debris flows result in poorly-sorted diamictons with crude internal stratification. Dating of surficial deposits is

problematic, hence traditional stratigraphy-based techniques are largely not applicable. The four-fold mapping protocol circumvents the need for formal stratigraphic nomenclature.

The map technique was systematically applied to three study areas in the central Appalachians, one of which was subject to debris-flow activity in June, 1949. Surficial mapping combined with slope analysis identifies gradients that are conducive to debris-slide failure. The example application suggests that a well-defined surficial map protocol combined with geographic information systems provide potentially powerful tools for the design of hazard mitigation plans. The technique offers a blueprint for design of surficial maps in other unglaciated, mountainous landscapes.

INTRODUCTION

Geologic mapping has a long tradition in the United States, dating to the western expeditions of Powell in the late 1800's (Powell, 1882; 1888). The National Geologic Mapping Act of 1992 recognized the importance of geologic mapping as a tool for resource evaluation, environmental protection, and natural hazards assessment. As a cartographic subset, surficial maps provide representation of the critical links between bedrock geology, climate, tectonics, vegetation, and surficial processes. Thus, surficial geology maps yield a spatial data set from which to evaluate models of landscape evolution, climate change, landscape ecology, and geomorphic hazards.

Studies in the central Appalachians provide the basis for many classic concepts in geomorphology (Davis 1889, 1899; Hack, 1960; Morisawa, 1989). The steep, rugged valleys of this region are associated with a long history of catastrophic flooding, slope failure, and debris flow (Shafer, 1988; Kochel, 1987, Eaton and McGeehin, 1997). Damage from these events has totaled billions of dollars with the loss of hundreds of lives (Williams and Guy, 1973; Brabb, 1989; Jacobson, 1993; Wieczorek et al., 1996). In addition, the region is experiencing continued development in the form of timber harvesting, highway construction, and recreational facilities. Increases in population density lead to human occupancy of geomorphically hazard-prone lands (Rosenfeld, 1994). The understanding of geomorphic processes is critical for the appropriate design of land-use regulations, hazards mitigation, and conservation planning. Well-designed maps provide a cost-effective and understandable form of scientific communication that is readily accepted by nontechnical policy makers. The initial step in development of hazards mitigation programs for the central Appalachian region is systematic mapping of fluvial, colluvial, and karst features.

No standardized criteria exist for adequately mapping flood and landslide hazards in the central Appalachians (Jacobson, 1993). This paper offers a blueprint for surficial mapping strategies in the unglaciated portion of the mountain region. The technique emphasizes the linkage between landforms, materials, and processes in a humid-mountainous landscape dominated by hillslopes, mass wasting, and fluvial erosion. This methodology is based on recent work in sandstone terrains of the Valley and Ridge and Appalachian Plateau (Taylor, Chapters 2, 3, 4; this volume). The objectives of this paper are to stimulate discussion among researchers in the region, and provide a frame of reference for designing map criteria in other unglaciated, humid-mountainous landscapes. The paper concludes with an example application and implications for regional hazards risk assessment.

PREVIOUS WORK

Few detailed surficial geology maps have been compiled for the unglaciated central Appalachians. Surficial deposits in this region receive little attention compared to those of glaciated or tectonically active areas (Mills and Allison, 1995a). Table 5-1 presents a compilation of existing surficial maps. Early maps include Denny (1956), Hack and Goodlett (1960), Hadley and Goldsmith (1963), Pierce (1966), and Fiedler (1967). More recent work includes Mills (1986, 1988), Schultz and others (1990), Whittecar and Ryter (1992), Froelich and others (1992), Jacobson (1993), Kite and others (1995), Morgan and others (1997), and Cenderelli and Kite (1998). Most of the maps listed are at a 1:24,000 scale or smaller. An exception is the work of Cenderelli and Kite (1998) in which they carefully mapped the effects of historic debris flow at a scale of 1:3,500. All mapping schemes recognize the importance of both colluvial and fluvial deposits in the central Appalachians; however, there is little agreement with respect to specific map protocol. Previous works listed in Table 5-1 employ one or more of the following criteria; references are listed by identification number in parentheses:

Table 5-1. Summary of Previous Surficial Geology Maps for the Central Appalachians.

I.D. No.	Reference	Year	Map Scale	Location	Map Units
1	Denny **	1956	1:24,000	Genessee 7.5-minute quadrangle, PA (south of glacial limit)	alluvium, alluvial fans, block fields, thin mantles, periglacial deposits
2	Hack and Goodlett	1960	1:33,300	Little River, Augusta County, VA	chutes and channels created by the cloudburst flood of June 1949; vegetation-landform associations (northern hardwood/hollows, oak/side slopes, yellow pine, noses-ridges)
3	Hack and Goodlett	1960	1:1,690	debris fan at locality 770, Little River, Augusta County, VA (Fig. 30, p. 54)	channel (no trees), 1949 high-water channel, gravel levee, slide surface (1949), debris fan (1949), woody debris piles, alluvial fan (1949), alluvial fan (older than 1949), flood plain, bedrock slopes mantled with block rubble and soil.
4	Hadley and Goldsmith **	1963	1:24,000	Dellwood 7.5-minute quadrangle, NC	alluvium, alluvium and colluvium, alluvial-colluvial fan deposits, terrace deposits
5	Pierce **	1966	1:24,000	McConnellsburg 7.5-minute quadrangle, PA	sandstone rubble, shale-chip rubble, gravelly alluvium, fine-grain alluvium, roundstone diamicton
6	Fiedler **	1967		Mountain Lake, Giles County, VA	scree, colluvium, roundstone diamicton
7	Godfrey **	1975		Catoctin-South Mountain, MD	boulder-covered slopes, side-slope stone streams, valley bottom stone streams, mountain wash
8	Lessing and others	1976	1:24,000	Appalachian Plateau, WV	landslide deposits and landslide-prone areas
9	Tewalt	1977		South Branch of Potomac, WV	alluvial terraces
10	Houser **	1980		Giles County, VA	colluvium, alluvium, boulder streams
11	Mills	1986	1:24,000	New River, southwest VA	low terrace and flood plain, intermediated terrace, high terraces (all relative to mean river level)
12	Mills	1988	1:24,370	Mountain Lake, Giles County, VA	residuum or bedrock (sandstone, shale, limestone), young colluvium, old colluvium, fine-medium-coarse young alluvium, older-weathered alluvium, bedrock terraces, boulder streams
13	Schultz and others	1990	1:100,000	Radford, VA 30 x 60 minute quadrangle	flood plain alluvium, terrace deposits, terraces, colluvium (boulder streams, boulder fields, talus, diamicton), "debris", large bedrock landslides, karst (sinkholes, cave openings, solution pinnacles), tufa deposits, residuum
14	Whittecar and Ryter	1992	1:39,400	western Blue Ridge, central VA	alluvial plain, lower debris fan, upper debris fan, colluvial slope, residual knob, talus slope, bedrock outcrop, boulder stream
15	Froelich and others	1992		Winchester, VA 20 x 60 minute quadrangle	colluvium and alluvium
16	Jacobson	1993	1:100,000	Wills Mountain anticline region, WV	residuum (includes thin colluvium, bedrock), colluvium, debris-flow deposits, alluvium / alluvial terrace

Table 5-1 (Cont.).

I.D. No.	Reference	Year	Map Scale	Location	Map Units
17	Kite and others	1995	1:24,000	Davis 7.5-minute quadrangle, Canaan Valley, WV	colluvium, residuum, alluvium, terrace, floodplain, fan, boulder field, boulder stream, karst (sinkhole, cave opening)
18	Mills and Allison	1995b	1:49,200 1:109,000	Hazelwood and Dellwood 7.5-minute quadrangles, NC	flood plain, terrace (young, old), fan (young, intermediate, old), saprolite, saprolite with gravel
19	Mills and Allison	1995c	1:39,400	Rich and Snake mountains, Zionville and Sherwood 7.5-minute quadrangles, NC	flood plain, saprolite, saprolite with gravel, fan surface (classified according to thickness of clast weathering rinds in mm)
20	Morgan and others	1997	1:24,000	Rapadan River basin, Madison County, VA	1995 flood erosion and deposition, flood plain not affected by 1995 storm, 1995 debris flow erosion and deposition, debris flow fans older than 1995, potential future debris-flow paths, slope gradients in degrees (<14, 14-26, 26-34, 34-45, >45)
21	Cenderelli and Kite	1998	1:2,800 1:3,000 1:3,500 1:3,800	North Fork Mountain, eastern WV	alluvium, stream channel, isolated boulders, boulder levee, tree levee, lobate boulder deposit, boulder terrace, boulder sheet deposits, diamicton, debris fan (classifed by age: pre-1949, 1949, post-1949, pre-1985, 1985, post-1985)
22	Jacobson	unpublished	1:24,000	Circleville 7.5-minute quadrangle, WV	slope colluvium (fine, medium, coarse), debris flow deposits (fine, medium, coarse), alluvium

** As cited by Mills, 1988

1. Process-based units: "residuum" (12,14,16,17), "colluvium" (4,6,10,12,13,15,16,17,22), "alluvium" (1,4,10,12,15,16,17,21, 22), "debris flow" (16,20,22), "periglacial deposits" (1), "karst" (13), "landslide deposits" (8), "mountain wash" (7);

2. Materials-based units: "sandstone rubble" (5), "gravelly alluvium" (5), "roundstone diamicton" (5,6), "diamicton" (13,21), "debris" (13), "saprolite" (18, 19), "saprolite with gravel" (18,19), "lobate boulder deposit" (21), "scree" (6), "bedrock" (12,14);

3. Landform-based units: "alluvial fans" (1,3,4), "thin mantles" (1), "chutes and channels" (2), "terrace" (4,9,11,13,16,17,18), "boulder-covered slopes" (7), "floodplain" (3,11,13,18,19), "boulder stream" (12,13,14), "debris fan" (14,21), "residual knob" (14), "talus slope" (14), "valley bottom stone streams" (7), "sinkhole" (13,17), "cave" (13,17);

4. Age-based units: "young/old colluvium" (12), "older weathered alluvium" (12), "young/old terrace" (18), "young/intermediate/old fan" (18), "1995 flood erosion and deposition" (20), "1985 / 1949 deposits" (21), "fan older than 1949" (3), "potential future debris flow paths" (20)

5. Clast weathering-rind units: "fan surface mapped on basis of clast-rind thickness" (19);

6. Heights of terrace surfaces: "0-25 m, 25-50 m, > 50 m" (11);

7. Slope gradient classes in degrees: "<14, 14-26, 26-34, 34-45, > 45" (20);

8. Vegetation-landform associations: "northern hardwood/hollows", "oak/side slopes", "yellow pine/noses-ridges" (2).

Although this important body of work provides a foundation for the recommendations presented herein, it is clear that a unified surficial map protocol is lacking for the central Appalachians. The absence of a systematic method results in widely varying data sets that are difficult to assimilate. Development of standardized surficial map criteria is necessary for effective data acquisition, information transfer, and process analysis.

SURFICIAL MAP CRITERIA

Methodology

The mapping protocol is based on similar schemes employed by the Maine Geological Survey (1986) and Kite (1994). These guidelines are designed to address the fluvial, colluvial, and karst features of the unglaciated Appalachians. The purpose of this map protocol is to: (1) provide an expanded, yet flexible, surficial map format for use in 7.5-minute quadrangle mapping, (2) provide a uniform approach to surficial mapping techniques in a field program that includes workers from various backgrounds, (3) provide a map-based data collection format that lends itself to geographic information systems, and (4) provide an approach to surficial mapping that is meaningful to planners, educators, consultants, and other user groups.

Three types of surficial map criteria are recognized for the central Appalachians (Taylor and others, 1996). These include: Type I - polygonal map units associated with landforms and surficial deposits; Type II - discrete surface features not associated with surficial deposits; and Type III - observational features associated with data collection and field mapping (Table 5-2). Type I units include landforms and deposits that result from *in-situ* weathering, mass wasting, fluvial processes, catastrophic slope failure, and periglacial activity. Type II units include surface features associated with karst processes, slope failure, surface hydrology, and anthropogenic activity. Type III features include reference points, test pits, and soil borings used for data collection. Type I mapping criteria employ a four-fold scheme in which units are delineated on the basis of age, origin, landform, and material. Unit polygons are coded with labels, patterns, or color to signify the four-fold designation. "Age" refers to the age of the material; "origin" refers to the primary surficial process responsible for deposition of the unit; "landform" refers to the topographic occurrence of the unit; and "material" refers to the texture of unconsolidated deposits or lithology of exposed bedrock. Type II and III criteria are mapped as two-dimensional surface features without reference to material or age.

The systematic nature of the map protocol is amenable to a checklist approach in recording field data (Table 5-2). The map feature is first identified as a Type I, II, or III element. A checklist format facilitates objective classification by the field worker. If a three-dimensional surfical deposit is encountered, then the Type I criteria are systematically examined, and the map feature is assigned age, origin, landform, and material identifiers. Additional map data include heights of surfaces above active channel, associated vegetation, and relative-age observations.

The optimum scale for surficial map preparation is largely determined by the intended use of the final product (Kite and others, 1998). Surficial geology maps can only be made for large areas in reasonable amounts of time if unit contacts can be derived from topographic and air photo interpretation, based on ground truth (Jacobson, unpublished report). A scale of 1:24,000

Table 5-2. Surficial Map Criteria for the Central Appalachians (after Kite, 1994).

A. Type I Criteria: Age, Origin, Landform, Material.

1. Age of Surficial Material

- H = Holocene (< 10,000 years old)
- W = Wisconsin (ca. 89 to 10 ka)
- I = Illinoian
- P = Pleistocene Undifferentiated
- EP = Early Pleistocene
- MPl= Middle Pleistocene
- LP = Late Pleistocene
- Q = Quaternary Undifferentiated
- CZ = Cenozoic Undifferentiated

2. Origin / Surficial Process

A. Hillslope
- r = residuum (in situ regolith)
- c = colluvium (mass wasting)
- ds = debris slide
- rf = rock fall or topple

B. Valley Bottom
- a = stream alluvium (normal flow)
- hcf = hyperconcentrated flow
- df = debris flow
- sw = slackwater deposition

C. Lacustrine
- l = lacustrine deposit, undiff.
- lb = lake-bottom deposit
- ld = lacustrine deltaic

D. Other
- g = glaciofluvial, undifferentiated
- go = glacial outwash
- e = eolian
- co = collapse (solution)
- cr = cryoturbation
- x = anthropogenic disturbance
- f = artificial fill
- rk = bedrock (process n/a)

3. Landform Units

A. Hillslope
- n = nose
- sl = side slope
- h = hollow
- veneer = < 2m of regolith
- blanket = > 2 m of regolith
- bf = boulder field
- bs = boulder stream
- pg = patterned ground
- tls = talus deposits

3. Landform Units (Cont.)

B. Valley Bottom
- ch = channel
- fp = floodplain (RI </= 2-3 yr)
- t = terrace (t1, t2 …tn; height AMRL)
- f = fan
- f-t = fan terrace (f1, f2 …fn; height AMRL)
- a = apron (footslope deposit)
- lo = lobe
- lv = levee
- ox = oxbow, abandoned channel

C. Other
- ft = flow track (debris flows)
- hm = hummocky topography
- rb = rock-block slide deposits
- x = excavated, fill, disturbed ground
- d = delta
- du = dune

4. Material (Composition and Texture)

- b = boulders (>256 mm; clast supported)
- c = cobbles (64-256 mm; clast supported)
- p = pebbles (4-64 mm; clast supported)
- g = gravel (>2 mm; clast supported)
- sg = mixed sand and gravel
- s = sand (0.05-2.0 mm)
- st = silt (0.002-0.05 mm)
- cy = clay (<0.002 mm)
- l = loam (mix of sand, silt, clay)
- d = diamicton undifferentiated
- bbd = very bouldery diamicton
- bd = bouldery diamicton
- cd = cobbly diamicton
- pd = pebbly diamicton
- ds = sandy matrix diamicton
- dt = silty matrix diamicton
- dy = clayey-matrix diamicton
- rk = bedrock (modify with lithology)
- rs = rotten stone, saprolite
- tr = travertine
- tu = tufa
- ma = marl
- og = organic-rich sediment
- w = water
- u = unkown

B. Type II Criteria: 2-D Surface Features

1. Karst
- bv = blind valley
- ca = cave (human entry)
- Active cave passage
- Abandoned cave passage
- dv = dry valley
- kw = karst window
- sk = sinkhole (doline)
- skst = sinking stream
- ks = karst spring

2. Hillslope
- hs = headscar
- ds = debris-slide scar
- ls = landslide scar undifferentiated
- rs = rotational slide (slump) scar
- ts = translational slide scar
- rb = rock-block slide scar
- tc = terracettes

3. Other
- wf = water fall
- w = water, lake, reservoir
- Spring
- wt = wetland, undifferentiated
- wh = wetland, heath
- wm = wetland, marsh
- ws = swamp
- quarry (with highwall)
- gravel pit
- deep mine opening
- strip mine (with highwall)
- mine subsidence zone
- rc = rock city
- Scarp
- Meander scroll on floodplain
- Lacustrine strandline

C. Type III Criteria: - Data Reference Points

- Sandwhich symbols showing stratigraphy
- Depth to bedrock (drilling or seismic data)
- Minimum depth to bedrock (log data)
- Test hole / boring
- Well
- RE = refusal (in test boring)
- Hand-auger hole, shovel hole,
- Fossil locality
- Paleocurrent direction
- Observation Point

works well for large fluvial landforms, but is inadequate for portraying most landforms produced by small streams or colluvial processes. A 1:10,000 scale is optimal for mesoscale landforms such as point bars, floodplains, terraces, debris fans, and boulder streams (Kite and others, 1998). Larger map scales are prerequisites for detailed reconstruction of processes at flood and debris-flow impacted sites (Wells and Harvey, 1987; Ohmori and Shimazu, 1994; Cenderelli and Kite, 1998). The 1:24,000 scale is the preferred mode for many mapping projects at the state and federal level; however, much process-oriented detail is lost due to generalization of map units. A 1:9,600 scale has proven quite effective for the delineation of process-landform associations in small (<60 km^2) mountain watersheds associated with this study (Taylor, Chapters 2, 3, 4; this volume).

Landform

Large-scale, bedrock-dominated landforms characterize the erosional landscape of the central Appalachians. Hack (1960, 1975) emphasized the importance of dynamic equilibrium in this region, where fluvial-dominated surface processes are in delicate equilibrium with bedrock structure and resistance to erosion. Bedrock-dominated landforms are generally evident from topographic maps, but the geometry of the overlying surficial deposit is not (Kite, 1994). The landform component presented in Table 5-2 addresses both the landscape feature (e.g. ridge) and overlying deposit geometry (e.g. residual veneer, <2 meters thick).

Large-scale landform units are classified into hillslope and valley-bottom features. Hillslopes feed into valley-bottom areas, conveying runoff and transporting sediment. These larger-scale landform units are comprised of smaller, mesoscale features delineated at the outcrop level and from contour patterns.

<u>Hillslope Regime</u>

Hack and Goodlett (1960) provided a framework for classification of hillslope elements in the central Appalachians. Many researchers outside the region recognize the importance of this seminal work (Marcus, 1980; Pierson, 1980; Dietrich and Dorn, 1984; Dietrich and others, 1986; Reneau and others, 1989; Montgomery and Dietrich, 1989). Following the approach of Hack and Goodlett (1960), hillslope landforms are subdivided into ridges, side slopes, hollows, and noses (Table 5-2, Figure 5-1, Figure 5-2). Ridges are upper-elevation areas in which contours are closed, acting as the primary divides between drainage basins. Side slopes represent open hillslope areas with approximately straight contour patterns. Hollows are defined as upland stream heads in which contours are concave outward in a down-slope direction. Tsukamoto (1973) coined the term "zero-order basin" to signify convergent slopes located above perennial first-order streams. For expediency in topographic-based mapping, hollows as defined here include the zero-order portion of the hillslope, as well as part of the first-order tributary with open-channel flow (after Mills, 1981). Hollows serve as the primary conduits for routing runoff and colluvium to higher order tributaries, and can occupy greater than 50% of total watershed area (Marcus, 1980). Noses represent divides between hollows in which contours are convex outward in a down-slope direction. Hack and Goodlett (1960) originally defined footslopes as transitional areas between side slopes and valley-bottom channels. For purposes of organization, the footslope environment is included within the discussion of valley-bottom landforms.

Deposit Geometry

Regolith geometry is an important consideration with respect to the style and magnitude of processes that operate. Dietrich and Dunne (1978) noted the importance of colluvial thickness and root penetration depth in controlling hillslope stability. As such, there is a strong tendency for regolith to thin on noses and thicken in convergent hollows (Reneau and Dietrich, 1987). Jacobson (unpublished report) suggested that these landform-thickness relationships are prevalent in the central Appalachians and topographic form is a guiding factor in determining depth to bedrock.

The map protocol outlined in Table 5-2 includes criteria for recognizing the thickness of regolith on larger-scale, hillslope landforms. The terms "veneer" and "blanket" are applied to regolith thicknesses less than 2 meters and greater than 2 meters, respectively. Landforms with no regolith cover are mapped as "bedrock". Thus, hillslope landforms and deposit geometry provide a three-dimensional characterization of the surficial environment. Using the landform-thickness relationships discussed above, Type I hillslope elements may include "nose veneer", "side-slope veneer", "hollow blanket", or "nose bedrock".

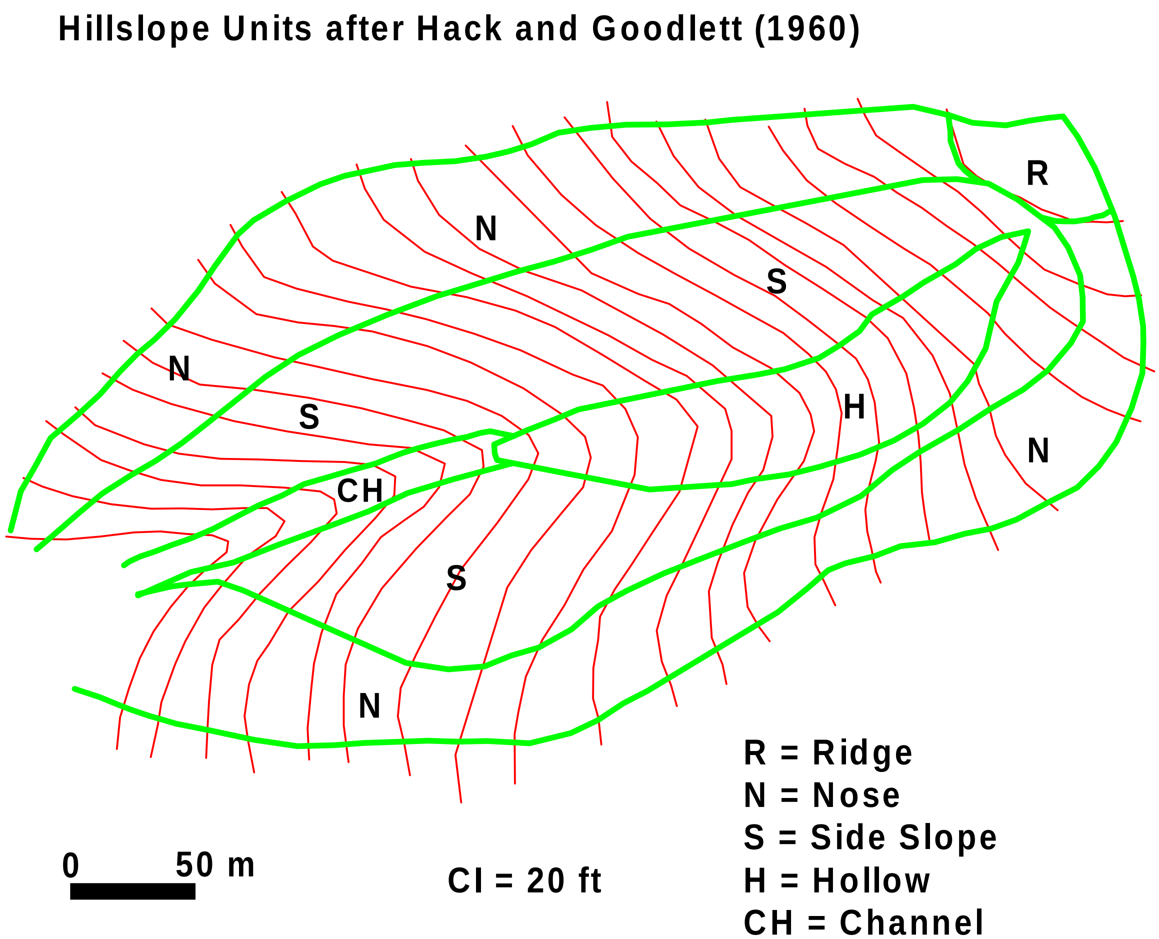

Figure 5-1. Hillslope landform elements after Hack and Goodlett (1960). Net transport flow paths are divergent on nose, covergent in hollows, and parallel on side slopes (Reneau and others, 1989). Noses represent drainage divides between zero- to first-order tributaries. Ridge crests serve as drainage divides between higher-order watersheds.

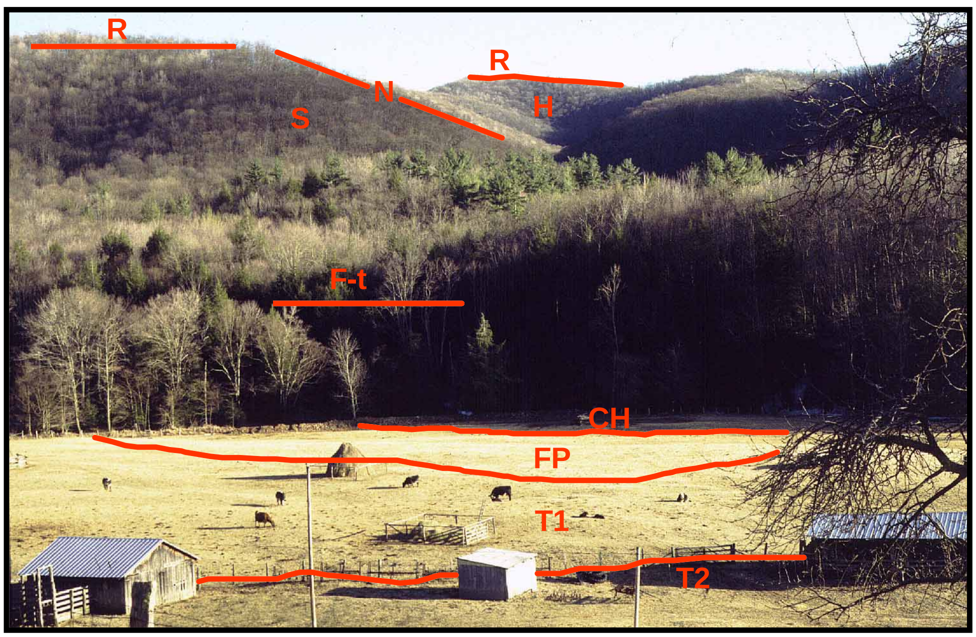

Figure 5-2. Principal landform elements recognized in the unglaciated, humid-mountainous landscape of the central Appalachians. Label identification is as follows: R = ridge, N = nose, S = side slope, H = hollow, CH = channel, FP = floodplain, T1 = low terrace, T2 = intermediate terrace, F-t = Fan terrace. Photograph is from the North Fork basin, Pocahontas County, West Virginia. See text for discussion.

Valley Bottom Regime

Valley bottoms represent lower elevation areas adjacent to stream channels. This zone is further subdivided into channels, floodplains, terraces, fans, and aprons (Figure 5-2; Figure 5-3). The channel is the zone occupied by open streamflow and includes the channel bed, depositional bar, and active-channel bank (Osterkamp and Hupp, 1984). Channel alluvium is subject to active reworking by streamflow for significant periods of the year, with negligible vegetative growth.

The floodplain is a low-lying surface adjacent to the channel that is inundated once every one to three years (Osterkamp and Hupp, 1984; Wolman and Leopold, 1957). In the central Appalachians, floodplain heights range from less than 1 meter (Taylor and Kite, 1999) to greater than 10 meters (Schultz and others, 1990) above channel grade, depending on size of the watershed.

Terraces are defined as elevated alluvial surfaces that are inundated by flood waters at a frequency less than that of the floodplain. The higher the terrace elevation above the channel, the less likely the occurrence of inundation, with the highest surfaces abandoned completely. Elongate terrace treads are commonly disconnected and unpaired, characterized by areas of anomalously flat topography. Low-level terraces are common in small Appalachian watersheds (<60 km^2) and range in heights from 2 to 8 meters above channel grade (Taylor and Kite, 1998). Strath terraces on larger drainage systems range up to 100 meters above mean river level (Mills, 1986; Jacobson and others, 1988; Schultz and others, 1990; Erikson and Harbor, 1998). The terrace map designations in Table 5-2 are labeled with a modifier to signify surface height above the nearest active channel (e.g. T1 = 2 to 4 m, T2 = 6 to 8 m, *etc.*). The height identification method precludes the need for obtaining chronologies prior to mapping terrace surfaces; however, flexibility in the protocol permits precise age assignment if data are available.

Although not as dramatic as in the southwestern United States, fan deposits are a common occurrence in the central Appalachians (see Kochel, 1990 for a review). In smaller-scale watersheds, poorly-sorted debris fans occur at the junctions of lower and higher order tributaries (Taylor, 1998). Similar types of deposits are described as "debris cones" elsewhere in the literature (Wells and Harvey, 1987; Kellerhals and Church, 1990). Larger-scale, more complexly organized fans are found in piedmont areas of the Blue Ridge, where lateral erosion provides greater accommodation space for fan growth and preservation (Kochel, 1990; Whittecar

Surficial Map Units

Qc1 - Quaternary colluvium (side-slope veneer, cobble- to boulder-diamicton)

Hch - Holocene channel deposits (alluvium; cobbles and boulders)

Hfp1 - Holocene floodplain alluvium (1-2 m above channel grade, loamy gravel)

Qt1 - Quaternary terrace deposits (2-4 m above channel grade; alluvium; gravelly loam)

Hf - Holocene (historic) fan deposits (debris flow, cobble- to boulder-diamicton)

Qf1 - Quaternary fan-terrace deposits (fan surface 2-4 m above active channel grade; debris flow?-alluvium; cobble- to boulder-diamicton)

Qf4 - Quaternary fan-terrace deposits (fan surface 8-10 m above active channel grade; debris-flow?-alluvium, cobble- to boulder-diamicton)

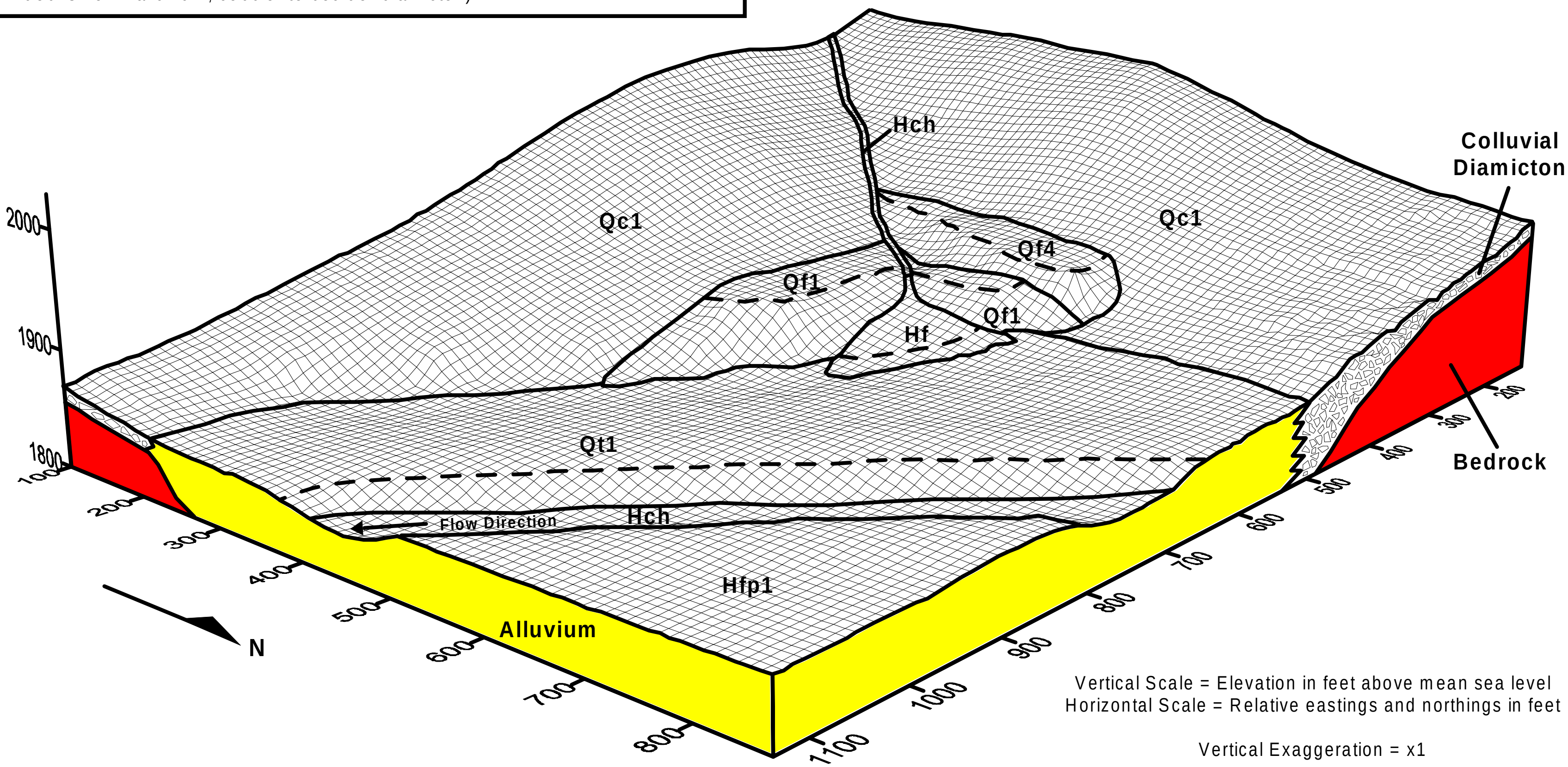

Figure 5-3. Generalized block diagram illustrating examples of valley-bottom landforms in the central Appalachians.

and Duffy, 1992; Mills and Allison, 1995b). Fans may become laterally and vertically incised to form abandoned fan terraces, with surfaces elevated well above the active channel floor (Mills, 1983; Whittecar and Duffy, 1992). Fan terrace surfaces range in height from 3 to 15 meters AMRL in small watersheds (Taylor, 1998), and greater than 20 meters in larger-scale fan environments (Mills and Allison, 1995a). Similar to terrace levels described above, fan surfaces are mapped according to height above channel grade (e.g. F = at grade, F1 = 2 to 4 m, F2 = 4 to 6 m, *etc*.; Figure 5-3). Large fans coalesce to form bajadas on the western slopes of the Blue Ridge (Whittecar and Duffy, 1992).

Colluvial aprons lie at the base of the hillslope and represent a zone transitional to the valley-bottom regime ("footslope" deposits of Hack and Goodlett, 1960). Aprons typically display a gentler gradient than the adjacent side slopes, and are commonly underlain by mass-wasting deposits. Lateral erosion of aprons by valley-bottom channels results in development of a steep scarp, with the apron surface appearing as an irregular, unpaired terrace.

Miscellaneous Landforms

Several Appalachian landforms represent mappable variations of the primary hillslope and valley-bottom features described above (Table 5-2). Miscellaneous hillslope features include boulder streams (Potter and Moss, 1968), boulder fields (Clark and Torbett, 1987), talus slopes (Whittecar and Ryter, 1992), patterned ground (Clark, 1968; Clark and Ciolkosz, 1988); rock-block slides (Schultz and Southworth, 1989), debris-slide scars (Clark, 1984; Mills and others, 1987), and debris-flow tracks (Clark, 1984; Mills and others, 1987). Miscellaneous valley-bottom landforms include lobes (Cenderelli and Kite, 1998), levees (Hack and Goodlett, 1960), oxbows, hummocky topography, and deltas. Type II karst features include cave openings, sinks, solution pinnacles, blind valleys, swallows, and karst springs (Davies, 1958; Schultz and others, 1990; Kite and others, 1995). Anthropogenically disturbed lands are mapped as "excavated", "fill", or "disturbed ground".

Materials and Origin (Process)

Table 5-2 summarizes the materials and origin criteria. Material refers primarily to the texture of surficial deposits overlying bedrock. Kite (1994) recommended use of the USDA textural classification for grain sizes less than 2 mm, since soil surveys are a common starting point for most surficial geologists. The Wentworth scale is recommended for clasts larger than 2 mm as the USDA designations lack geomorphically significant detail. Bedrock exposure is an important component of the geomorphic system and is included as a materials unit. The origin criteria refer to the dominant processes resulting in the surficial deposit. Process interpretations are based largely on facies and landform analysis, and by comparison with deposits of a known origin. The process identifiers are not applied to bedrock map polygons.

Similar to landforms, surficial material is also divided into hillslope and valley-bottom facies. Hillslope deposits include colluvium and residuum, while valley-bottom deposits include channel alluvium, floodplain alluvium, terrace sediments, fan deposits, and apron deposits.

Hillslope Deposits

Colluvium and residuum are the most widespread surficial deposits in the central Appalachians (Mills and Delcourt, 1991). Both facies are comprised primarily of gravel diamicton in which framework clasts are set in a matrix of loamy sand, silt, and clay. Parent lithology is the primary influence on clast composition and texture. The term "regolith" encompasses all weathered and transported sediment at the earth's surface. "Colluvium" is applied to regolith that has been transported and deposited by diffusive mass-wasting processes (Mills and Delcourt, 1991). These processes are gravity driven and include slope wash, creep, frost heave, tree throw, and bioturbation. Under conditions of significant down-slope transport, the clast composition of colluvial sediments may differ significantly from that of the underlying bedrock (Mills, 1981). "Residuum" by definition contains the *in-situ* products of bedrock weathering. Clast composition represents parent bedrock lithology, with little or no transport (Mills, 1988). Hillslope colluvium and residuum most commonly form depositional veneers on bedrock, with thicknesses less than two meters. Residual veneers develop on ridge crests and noses with gentle slope gradients. Colluvial veneers occur on steeper side slopes.

Based on landform-deposit relationships, hillslope colluvium is subdivided into side-slope / nose facies (Qc1) and hollow facies (Qc2; Table 5-2). Many researchers have recognized the importance of hollows with respect to hillslope sediment routing and hydrologic processes (Hack and Goodlett, 1960; Williams and Guy, 1973; Dietrich and Dunne, 1978; Anderson and Burt, 1978; Pierson, 1980; Dietrich and Dorn, 1984; Marron, 1985; Hayes, 1985; Reneau and

Dietrich, 1987; Tsukamoto and Minematsu, 1987; Crozier and others, 1990; Dietrich and others, 1995). Local topographic curvature determines whether material transport follows flow paths that are divergent (noses), convergent (hollows), or parallel (side slopes) (Hack and Goodlett, 1960; Reneau and others, 1989). Reneau and others (1984) concluded that thick deposits of hollow colluvium are important sources of debris flow and constitute a mappable geologic hazard. Hollow colluvium accumulates by diffusive mass-wasting processes. Debris slides are initiated during high-intensity precipitation events, in which positive pore pressures develop and critical shear strength is exceeded (Anderson and Burt, 1978; Pierson, 1980). The lower the bedrock permeability compared to that of hollow colluvium, the less stable the hillslope (Dietrich and others, 1995). Debris slides rapidly transform into debris flows as they mobilize into higher-order tributaries (Costa, 1984). Dietrich and Dunne (1978) noted the importance of regolith thickness with respect to slope failure, as thicker colluvium reduces the probability of root penetration to bedrock, lowering net effective shear strength. Therefore, the recurrence interval for episodic debris flow depends on the rate of colluviation, and the return time for triggering rainfall events (Costa and Jarrett, 1981). The rate of colluvial transport in turn, is directly proportional to the slope gradient (Dietrich and others, 1995). These hollow models are partially validated by flood-damage assessments in the central Appalachians. Williams and Guy (1971) noted that during the 1969 Nelson County debris flow event in Virginia, 85% of debris slides originated in preexisting hillslope depressions. Hack and Goodlett (1960) made a similar observation for 1949 slope failures in the Little River basin of Augusta County, Virginia. Thus, hillslope hollows represent a geomorphically significant element of the Appalachian landscape and special consideration is warranted in surficial mapping schemes.

Boulder streams and boulder fields are a common occurrence in the central Appalachians, and represent a mappable subset of colluvium. Boulder streams are elongate in the down-slope direction and tend to armor low-order tributaries. They are recognized by a prominent bouldery surface cover, with negligible amounts of finer-grained, interstitial sediment (Mills and Delcourt, 1991). Boulder fields are similar in character, but occur along straight side slopes and display an equant or irregular shape. Boulder streams and fields likely form by a combination of sliding, creep, and slopewash winnowing. It is plausible that better developed boulder streams are the products of periglacial processes during Pleistocene glacial climates (Clark and Torbett, 1987;

Mills, 1988; Mills and Delcourt, 1991; Whittecar and Ryter, 1992). Supporting evidence is provided by numerous occurrences of patterned ground throughout the central Appalachians, documenting the widespread nature of periglacial conditions south of the glacial limit (Clark and Ciolkosz, 1988). The minimum elevation of patterned ground increases with decreasing latitude, from 600 meters along the glacial border to 1500 meters in more southerly latitudes (~35° N; Mills and Delcourt, 1991). Geo-botanical analysis of forest cover in Virginia suggests that some steep (35-40°) boulder fields are active under present-day climate conditions (Hupp, 1983).

<u>Valley-Bottom Deposits</u>

Valley-bottom facies are comprised primarily of coarse gravel with various admixtures of loam, sand, and silt. These deposits are associated with channels, floodplains, terraces, fans, and aprons. Cobble- to boulder-dominated channels are common in steep mountain watersheds. Channel alluvium is typically clast supported, moderately sorted, and imbricated due to deposition by turbulent streamflow.

Floodplains and terraces are similarly comprised of coarse gravel deposits with loamy interbeds. Fabrics range from matrix- to clast-supported. Evidence for frequent floodplain inundation includes scour-and-chute topography, disturbed vegetation, and fresh slackwater deposits. Higher terrace surfaces display stabilized vegetation and are elevated well above flood-discharge level. Distinguishing between low terrace and floodplain is problematic because both surfaces are irregular. (Leopold and others, 1964). Osterkamp and Hupp (1984) argued that vegetative patterns are the most reliable criteria for distinguishing between the two. Floodplains and terraces are the products of fluvial incision, lateral channel migration, and overbank aggradation (Leopold and others, 1964; Nanson, 1986).

Fan deposits in sandstone landscapes of the central Appalachians are cobble- to boulder-rich, massive to crudely stratified, with either matrix- or clast-supported fabrics. Matrix fractions are in the silty to sandy loam class. Debris-fan deposits occur at tributary junctions as a result of flow expansion and decreased stream power (Taylor, Chapter 6, this volume). More sand-dominated, braided-fluvial fans are located on the western flanks of the Virginia Blue Ridge (Kochel and Johnson, 1984). Debris fan exposures reveal a complex internal stratigraphy with inset facies relationships (Kite, 1987; Tharp, unpublished data; Figure 5-4). Most of the higher

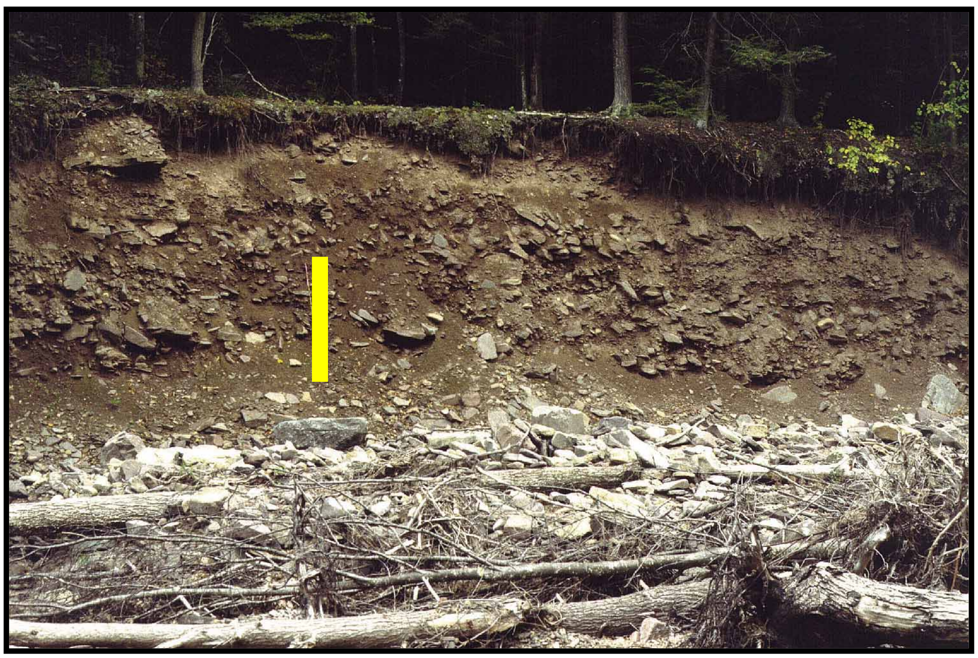

Figure 5-4. Photo showing example of complex internal stratigraphy from a 5 to 6 m fan terrace in the central Appalachians. Note abundance of cobble- to boulder-diamicton and crude stratification. Yellow bar is 2 m.

fan terraces are dissected and covered with a colluvial veneer. Fans in the central Appalachians are the products of a combination of debris flow, hyperconcentrated flow, and normal streamflow (Mills, 1982; Kochel, 1990). The debris flows derived from sandstone regolith are noncohesive, resulting in poorly-sorted diamictons with crude internal stratification. Clast-supported and imbricated gravels result from fully turbulent streamflow (after Smith, 1986). Footslope aprons are similar in texture and occurrence, but they lack a well-defined point source. Aprons are the result of mass-wasting processes, such as slide, creep, and slope wash.

Age

Dating of surficial deposits in the Appalachians is problematic, and persists as an elusive facet of geomorphic study. Geo-botanical evidence provides an important dating tool for historic deposits (Osterkamp and others, 1995); however, the ages of older landforms are poorly constrained. Radiocarbon techniques are of limited value due to poor preservation of organic matter and many older deposits are beyond the range of application (Mills, 1986; Mills and Delcourt, 1991). Thermoluminescence (Shafer, 1988), magnetostratigraphic (Jacobson and others, 1988; Springer and others, 1997), and cosmogenic isotope (Pavich and others, 1985; Granger and others, 1997; Ries and others, 1998) techniques provide results holding some promise; however, they have not yet been widely applied in the Appalachians. In addition, costly absolute dating techniques add greatly to mapping budgets, which are chronically underfunded and typically limited to field expenses. Relative-age dating techniques were utilized in several studies (Mills, 1988; Whittecar and Duffy, 1992; Mills and Allison, 1995b), although the discontinuous nature of surficial deposits makes stratigraphic correlation difficult. Pollen stratigraphy is applicable in upland bogs and on the Coastal Plain (Delcourt and Delcourt, 1986), but application in colluvial environments has not been tested. Mills (1988) concluded that a continuum of relative ages exists for many deposits with no discrete mappable groups. Hence, a traditional stratigraphy-based mapping scheme is largely not applicable due to poor resolution of surficial chronologies (Kite, 1994).

Table 5-2 provides criteria for assigning ages to surficial map units. Grouping deposits by age is often arbitrary and speculative at best. Historic channel and debris-flow deposits are mapped with certainty as "Late Holocene"; however, many older deposits are typically assigned an age of "Quaternary-undifferentiated". Despite the problematic uncertainties of surficial chronologies in the central Appalachians, the map protocol is flexible and offers precise age identification when data permit. Since the mapping scheme incorporates the four-fold criteria system described above, the need for formal stratigraphic nomenclature is largely unnecessary.

EXAMPLE MAP APPLICATION

Statement of the Problem

The map technique outlined above was systematically applied to three study areas in the central Appalachians (Taylor, Chapters 2, 3, 4; this volume). These areas include the Fernow Experimental Forest, Tucker County, West Virginia (19 km^2); the North Fork drainage basin, Pocahontas County, West Virginia (49 km^2); and the Little River basin, Augusta County, Virginia (42 km^2) (Figure 5-5). The Fernow and North Fork areas are located in the folded portion of the Appalachian Plateau, while the Little River lies in the Valley and Ridge. All three areas are similarly forested (northern hardwood and mixed hardwood forests), of the same soils composition (Typic Dystrochrepts), underlain by gently-folded strata of the Acadian clastic wedge, and subject to flood-generating storm events.

The Fernow and North Fork are characterized by narrow V-shaped valleys with colluvial and residual veneer as the dominant deposits (Taylor, Chapters 2, 3, 4; this volume). Valley bottoms possess only modest amounts of fan and alluvial deposits in storage, suggesting that the local transport systems are relatively effective at removing weathered material from the landscape (Taylor, 1998). Neither area shows evidence of Late Holocene debris flow activity. In contrast, the Little River basin was the location of storm-related debris flow in June of 1949 and bouldery valley fill is abundant (Hack and Goodlett, 1960). The present landscape is conspicuously associated with the erosional and depositional features produced by the 1949 event. Evidence for historic debris flow includes: (1) revegetated slide scars in zero-order hollows, (2) scoured bedrock surfaces in low-order tributaries, (3) scratches and striations in bedrock-scoured channels, (4) boulder levees, (5) fresh, poorly-sorted fan deposits (Figure 5-6), (6) disturbed vegetation dominated by colonizing species, and (7) bouldery, lobate fan fronts. Similar features are documented elsewhere in debris-flow impacted areas (Benda and Dunne, 1987; Costa, 1984; Wohl and Pearthtree, 1991; Kellerhals and Church, 1990; Wieczorek and

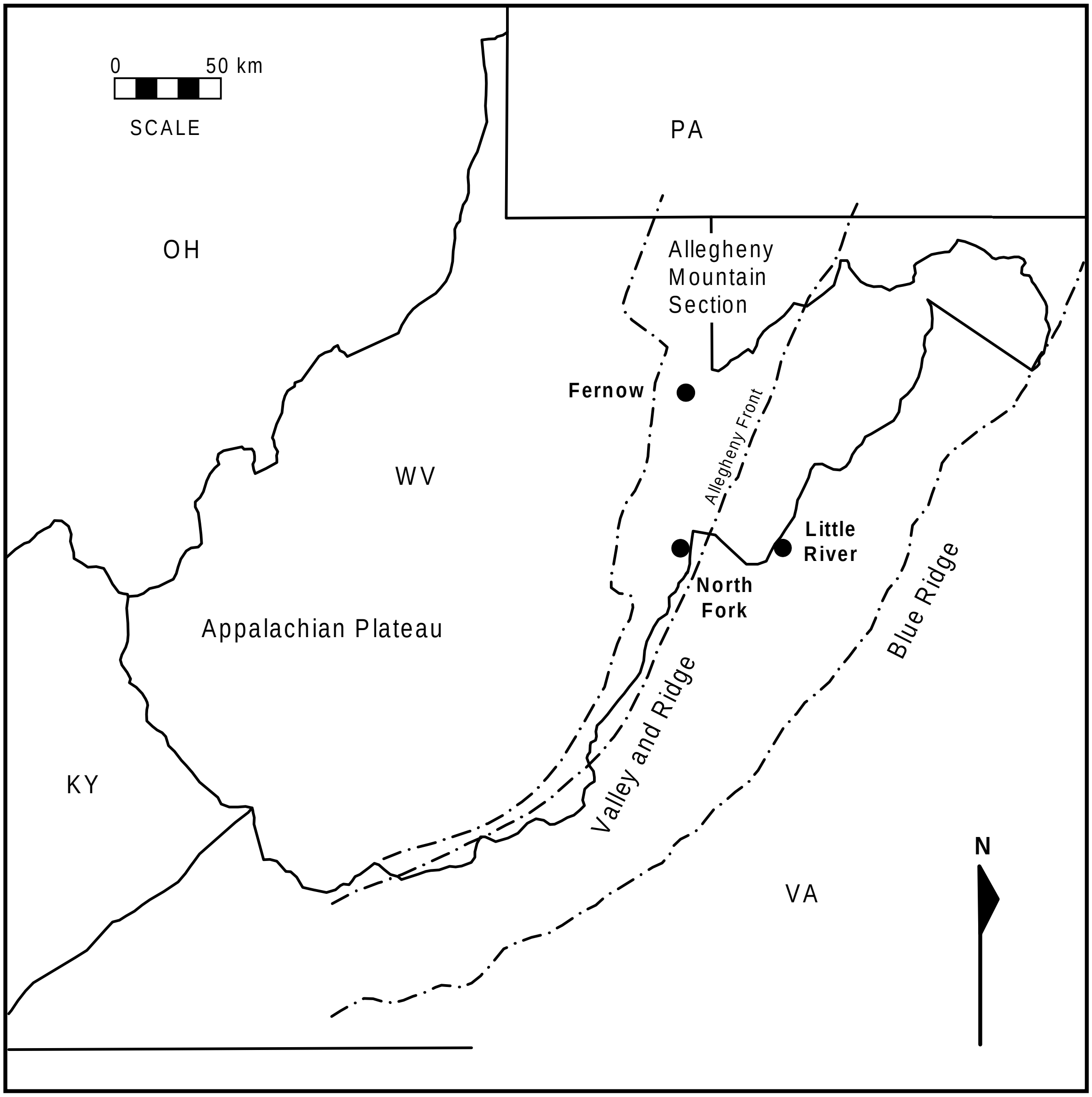

Figure 5-5. Physiographic map of the central Appalachians. Site identification codes are as follows: "Fernow" = Fernow Experimental Forest, Tucker County, West Virginia; "North Fork" = North Fork basin, Pocahontas County, West Virginia; "Little River" = Little River basin, Augusta County, Virginia. Physiographic base map is from Kulander and Dean (1986).

Figure 5-6. Bouldery debris-flow deposit from the June, 1949 event at the Little River basin, Augusta County, VA. Note buried basal rootflare of large-diameter hemlock and disturbed appearance of small-diameter birch on fan surface. Yellow bar is 2 m.

others, 1996; Cenderelli and Kite, 1998). Although all three areas are similar with respect to gross geologic and physiographic characteristics; the Little River is associated with more energetic hillslope transport events and a higher volume of surficial material in storage along valley bottoms (Taylor, 1998).

A comparative mapping study was completed with the goal of using the Little River as a benchmark for comparison with the Fernow and North Fork areas. Part of the objective was to further delineate local geologic controls on the occurrence of debris flow in the central Appalachians.

Methodology

Base maps were digitally converted from U.S. Geological Survey 7.5-minute quadrangles by automated vectorization procedures. The final topographic base was compiled with a contour interval of 40 ft and scale of 1:9,600. Spatial data were manually digitized and incorporated into a GIS database using a combination of AutoCAD (Autodesk, 1992), Idrisi (Clark Labs, 1997), and ArcView (Environmental Systems Research Institute, 1996). Surficial data were compiled using county soil surveys (Losche and Beverage, 1967; Hockman and others, 1979; Natural Resources Conservation Service, in press), natural exposures, topographic analysis, and aerial photography. Figure 5-7 and Table 5-3 present examples of surficial map products for the Little River basin.

To test the hypothesis that hillslope gradient is a controlling factor in the occurrence of debris flow, Idrisi was used to compare the surficial map data with slopes derived from 30-meter digital elevation models (U.S. Geological Survey). The slope analysis focused on debris-flow source areas in the hillslope-colluvium regime (units Qc1 and Qc2; refer to Table 5-3 and Figure 5-7). The working hypothesis was that Little River hillslopes tend to cross the critical threshold for debris-slide failure, while those at the Fernow and North Fork areas do not. This hypothesis is predicated by the need for high-magnitude precipitation events to trigger slope failure.

Results

The map units identified for the Little River (Table 5-3) are representative of the full spectrum of landforms, materials, and processes associated with Appalachian watersheds. Figures 5-8 and 5-9 present the results of slope analyses for hillslope map units Qc1 (noses / side slopes)

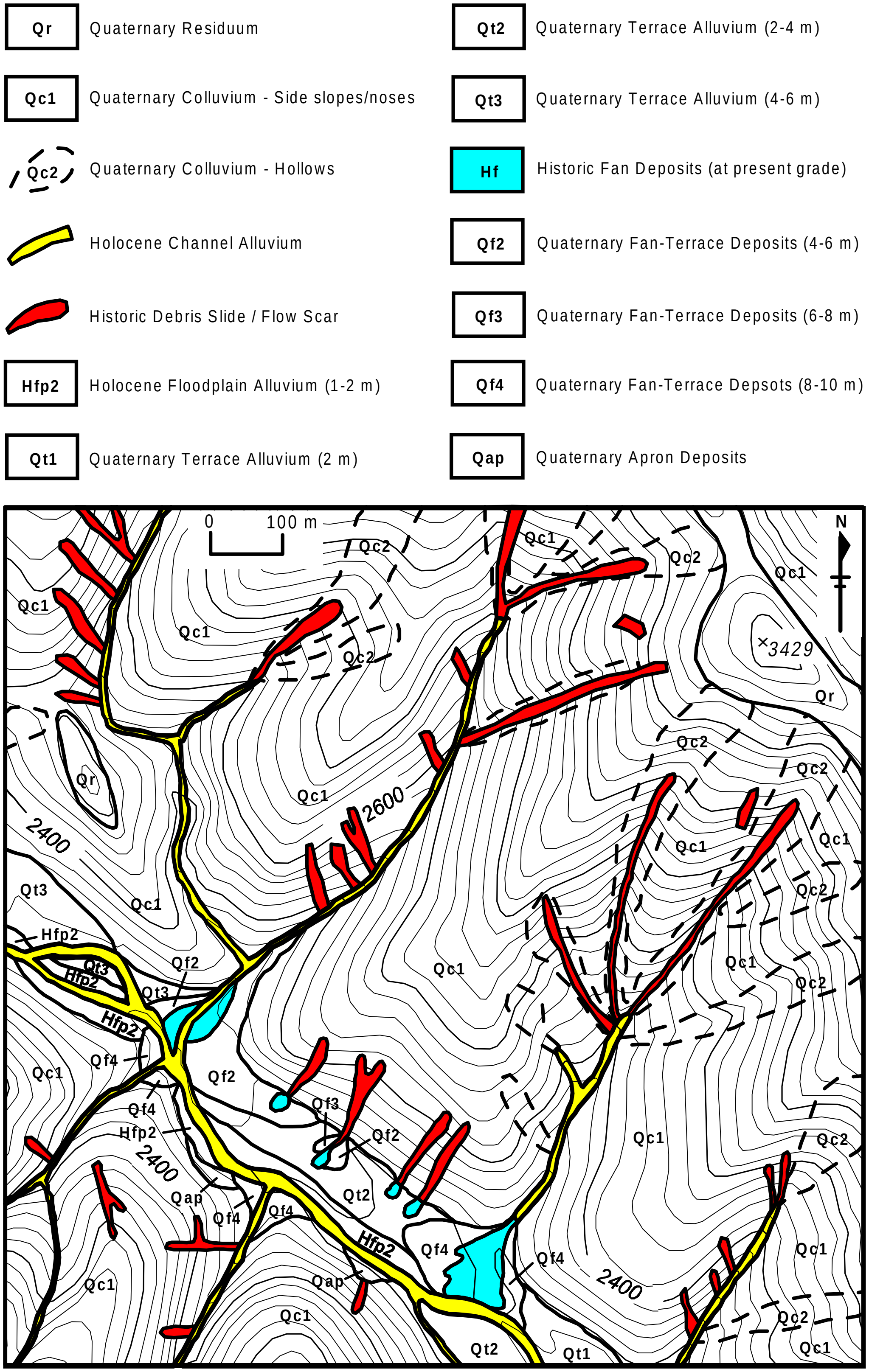

Figure 5-7. Portion of the surficial geology map for the Little River area, Augusta County, Virginia. Features were originally mapped at a scale of 1:9,600 (Taylor and Kite, 1998). Refer to Table 5-3 for an expanded explanation of map units. Contour interval = 40 ft.

Table 5-3. Example Application of Surficial Map Criteria at the Little River Basin, Augusta County, VA.

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qr	Quaternary Residuum	Quaternary (Undiff.)	Residuum	Ridge-Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,r,r-v,c-bdt-l)	Predominantly associated with ridge crests supported by the Pocono Formation.
Qc1	Quaternary Colluvium (Side Slopes)	Quaternary (Undiff.)	Colluvium	Nose-Side Slope Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c1,n/s-v,c-bdtl)	Predominantly associated with side slopes underlain by the Hampshire Formation. Includes the Hazleton and Hazleton-Lehew soils series (Hockman and others, 1979).
Qc2	Quaternary Colluvium (Hollows)	Quaternary (Undiff.)	Colluvium	Hollow Veneer	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c2,h-v,c-bdt-l)	Predominantly associated with zero- to first-order hollows underlain by the Hampshire Formation.
Qbf	Quaternary Boulder Field	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Field	Cobbles and Boulders	(Q,c,bf,c-b)	Equant to irregularly shaped side slopes covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Qbs	Quaternary Boulder Stream	Quaternary (Undiff.)	Colluvium (periglacial?)	Boulder Stream	Cobbles and Boulders	(Q,c,bs,c-b)	Elongate valley-bottom areas covered by greater than 80% cobbles and boulders. Commonly interpreted as the product of Pleistocene periglacial slope processes.
Hch	Holocene Channel Alluvium	Holocene	Alluvium	Channel and Narrow Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,ch,c-b-pl)	Fluvial channel deposits associated with first- to sixth-order streams. Unit includes channel alluvium and portions of adjacent floodplain too small to map at the given scale.
Hfp1	Holocene Floodplain Alluvium (0.5 to 1.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp1,c-b-pl)	Floodplain alluvium associated with second- to sixth-order streams. Unit includes low-lying surfaces 0.5 to 1.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(H,a,fp2,c-b-pl)	Floodplain alluvium associated with second- to sixth-order streams. Unit includes low-lying surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years.
Hfp2A	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Sandy Loam	(H,a,fp2A,s-l)	Sandy slack-water deposits upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Buried root flares common.

Table 5-3 (Cont.).

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Hfp2B	Holocene Floodplain Alluvium (1.0 to 2.0 m surface)	Holocene	Alluvium	Floodplain	Clayey Loam	(H,a,fp2B,cy-l)	Clayey slack-water deposits immediately upstream from Hearthstone Lake. Unit includes low-lying surfaces 1.0-2.0 m above present channel grade with a flood recurrence interval of approximately 3 to 5 years. Mud cracks and buried root flares common.
Hd	Holocene (Historic) Delta Deposits	Holocene (Historic)	Lacustrine Delta	Delta	Sandy Loam	(H,ld,d,s-l)	Historic lacustrine delta deposits associated with the flood-control reservoir at Hearthstone Lake.
Qt1	Quaternary Low-Terrace Alluvium (2.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace (Floodplain?)	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t1,c-b-pl)	Low-terrace deposits associated with second- to sixth-order streams. Unit includes low terrace surfaces 1.0 to 2.0 m above present channel grade with a flood recurrence interval greater than 5 years.
Qt2	Quaternary Terrace Alluvium (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t2,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 2.0 to 4.0 m above present channel grade.
Qt3	Quaternary Terrace Alluvium (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t3,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Qt4	Quaternary Terrace Alluvium (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium	Terrace	Cobbles-Boulders and Pebbly Loam (rounded to subrounded)	(Q,a,t4,c-b-pl)	Terrace deposits associated with third- to sixth-order streams. Unit includes terrace surfaces 4.0 to 6.0 m above present channel grade.
Hf	Holocene (Historic) Fan Deposits (undissected)	Holocene	Alluvium - Debris Flow(?)	Fan	Cobbles and Boulders, Gravel Diamicton	(H,a-df?,f,c-bdt-l)	Historic fan deposits commonly associated with first- to second-order hollows at stream-tributary junctions. Identified by fresh deposits, disturbed and buried vegetation. Primarily the result of June 1949 flood event.
Qf	Quaternary Fan Deposits (undissected)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f,c-bdt-l)	Fan deposits commonly associated with first-order hollows at stream-tributary junctions. Identified by older tree stands and lack of fresh appearance.
Qf1	Quaternary Fan-Terrace Deposits (2.0 to 4.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f1,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.

Table 5-3 (Cont.).

Map Unit Label	Map Unit Description	Age	Origin (Process)	Landform	Material (Texture)	Four-Fold Identifier	Comments
Qf2	Quaternary Fan-Terrace Deposits (4.0 to 6.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f2,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf3	Quaternary Fan-Terrace Deposits (6.0 to 8.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f3,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf4	Quaternary Fan-Terrace Deposits (8.0 to 10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f4,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qf5	Quaternary Fan-Terrace Deposits (>10.0 m surface)	Quaternary (Undiff.)	Alluvium - Debris Flow(?)	Fan	Cobble- to Boulder-Diamicton with Silty Loam Matrix (subangular to rounded)	(Q,a-df?,f5,c-bdt-l)	Entrenched fan surfaces commonly located at stream tributary junctions. Diamicton may be crudely stratified with imbricated gravely-loam facies.
Qap	Quaternary Apron Deposits	Quaternary (Undiff.)	Colluvium	Apron	Cobble- to Boulder-Diamicton with Silty Loam Matrix	(Q,c,ap,c-bdt-l)	Footslope deposits > 2.0 m in thickness. Commonly located at break in gradient between steeper side slopes and valley-bottoms.
Hds	Holocene (Historic) Debris Slide / Flow Scar	Holocene (Historic)	Debris Slide / Debris Flow	Scar	Commonly Scoured to Bedrock	(H,ds/df,sc,rk)	Slide scars associated with the June 1949 flood event. Debris slides transformed into debris flows with attendant erosion of surficial materials to bedrock. Identified by youthful and disturbed vegetation. Bedrock surfaces may be scratched and striated.

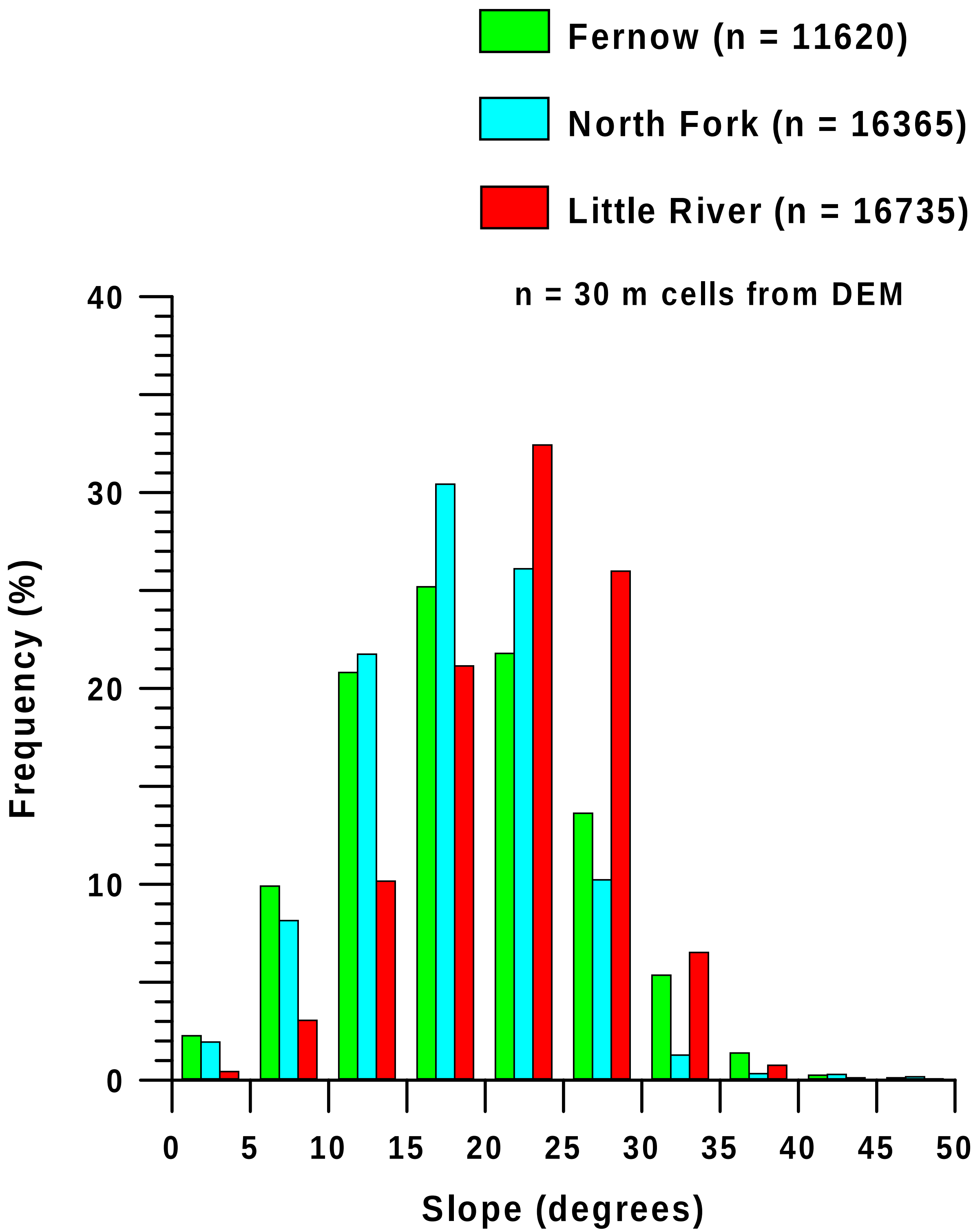

Figure 5-8. Bar graph showing slope distribution for Qc1 surficial map polygons (Quaternary colluvium: side slopes and noses). Data derived from 30-m USGS DEM's using the slope analysis algorithm of Idrisi for Windows (ver. 2.0). Frequency represents the numbers of 30 m x 30 m cells; slope values are presented in 5-degree bins. Mean Qc1 slopes are as follows: Fernow = 18.7 ^{o}, North Fork = 19.5 ^{o}, and Little River = 21.6 ^{o}.

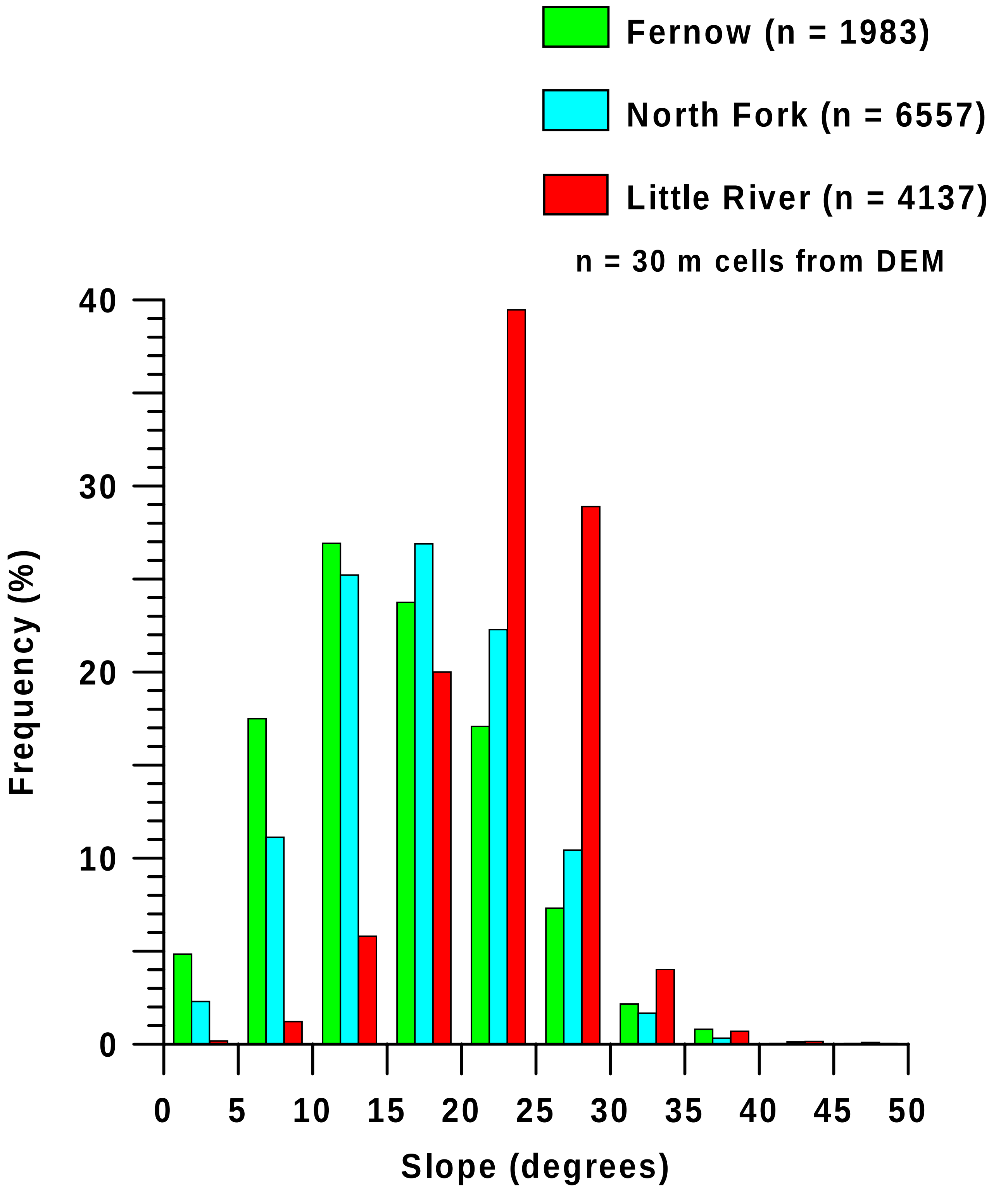

Figure 5-9. Bar graph showing slope distribution for Qc2 surficial map polygons (Quaternary colluvium: hollows). Data derived from 30-m USGS DEM's using the slope analysis algorithm of Idrisi for Windows (ver. 2.0). Frequency represents numbers of 30 m x 30 m cells; slope values are presented in 5-degree bins. Mean Qc2 slopes (degrees) are as follows: Fernow = 15.7^{o}, North Fork = 17.2^{o}, Little River = 22.6^{o}.

and Qc2 (hollows), respectively. The data show that Little River hillslopes are significantly steeper than those at the Fernow or North Fork areas. Site averages for Qc1 slopes are 21.6º, 18.7º, and 19.5º; while those for Qc2 slopes are 22.6º, 15.7º, and 17.2º, respectively. T-test analysis at the 95% confidence level reveals that hillslopes at the Little River are significantly steeper in both instances. The mode of slope distribution for the Little River is in the 20º to 25º range, while that for the Fernow and North Fork areas is 15º to 20º. Comparison with other debris-flow-prone areas in the Appalachians suggests that slopes of 25º to 30º represent a critical threshold for catastrophic slope failure (Williams and Guy, 1973; Jacobson and others, 1993; Graham, 1996; Morgan and others, 1997; Cenderelli and Kite, 1998). Greater than 30% of Little River hillslopes are at or above this range. In a separate analysis, over 60% of the "chutes and scars" mapped by Hack and Goodlett (1960) are on hillslopes with gradients greater than 20º (Figure 5-10). These slope data support the hypothesis that the Little River is more prone to debris flow compared to the other areas. This hypothesis is also supported by systematic field mapping and sediment volume calculations presented elsewhere (Taylor, Chapters 2, 3, 4, 8, this volume). Although beyond the scope of this discussion, sandstone lithofacies relationships in the Acadian clastic wedge are interpreted as the primary factor controlling the observed variations in hillslope gradients (Taylor, 1997; Taylor, Chapter 7, this volume).

The example results suggest that a well-defined surficial map protocol combined with geographic information systems provide potentially powerful tools for the design of hazard mitigation plans in regions prone to flood and debris flow.

CONCLUSION

Surficial geology maps yield a spatial data set from which to evaluate models of landscape evolution, climate change, landscape ecology, and geomorphic hazards. Surficial maps also provide the primary tool for geomorphologists to communicate concepts of process and landform to nontechnical policy makers and the general populace. A well-designed, standardized mapping technique is the prerequisite for promoting use of surficial maps. A unified mapping scheme also provides future end-users a consistent data set from which to conduct further research or apply engineering-design strategies. From an academic perspective, systematic mapping permits

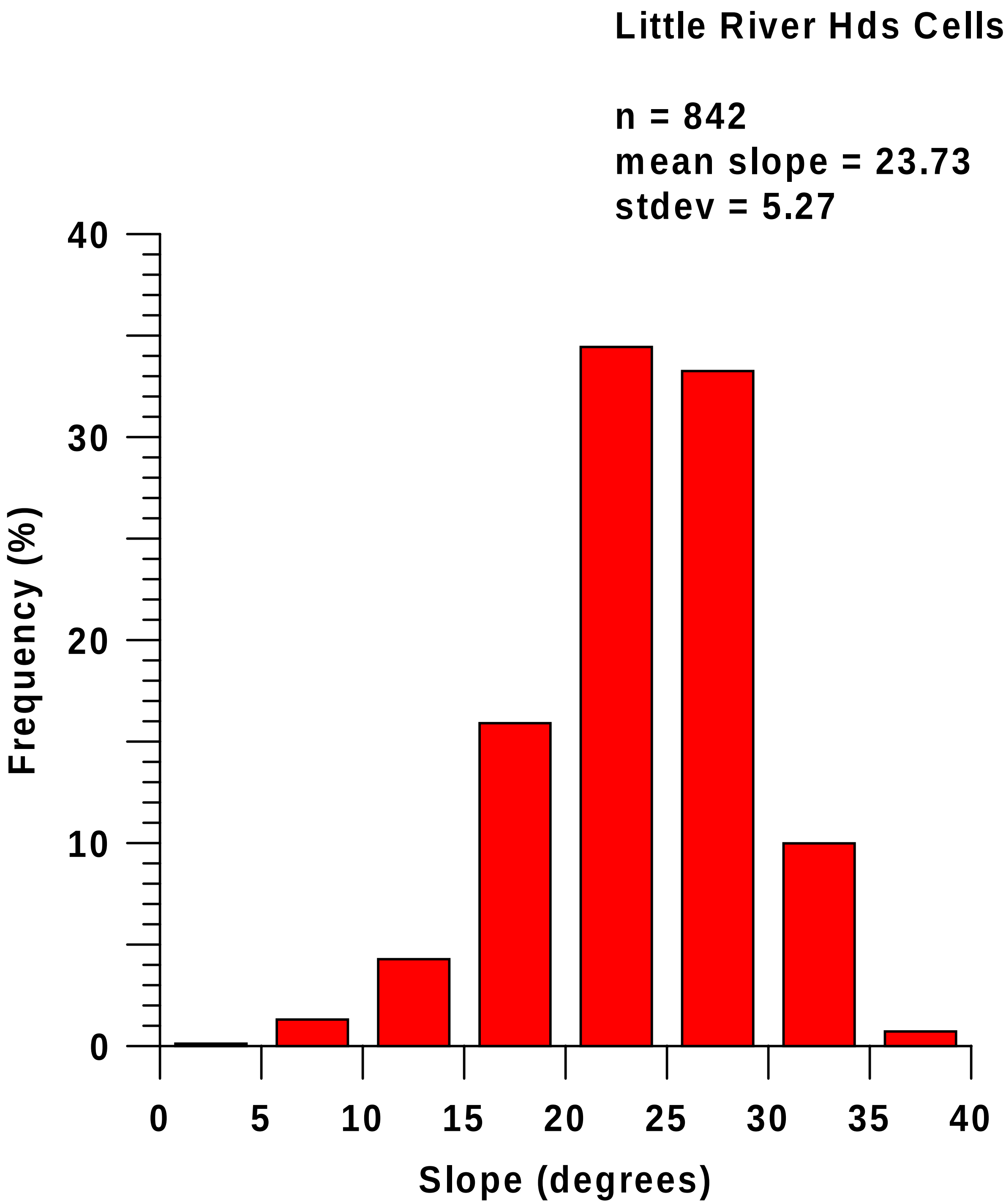

Figure 5-10. Slope distribution (degrees) for 1949 debris-flow "chutes" at the Little River area, as mapped by Hack and Goodlett (1960). The data set only includes scars mapped on side slopes and hollows, it does not include "flood channels" in the higher-order tributaries. Data derived from 30-m U.S.G.S. DEM's using the slope analysis algorithm of Idrisi for Windows (ver. 2.0). Frequency represents number of 30 m x 30 m cells. Note that slide-scar polygons are mapped on steep hillslopes and extend into more gently sloping valley bottoms.

watershed-scale comparison of sediment routing mechanisms, sediment storage volumes, and factors controlling sediment transport efficiency.

The map protocol presented herein offers a blueprint for design of surficial maps in unglaciated, humid-mountainous landscapes. The technique emphasizes the linkage between landforms, materials, and processes; while circumventing the need for absolute chronologies and formal stratigraphic nomenclature. Surficial geology maps combined with geographic information systems offer potentially powerful tools for the design of hazard mitigation plans in regions prone to flood and debris flow.

DOCUMENT LINKS: Contents Chapter 1 Chapter 2 Chapter 3
Chapter 4 Chapter 5 Chapter 6 Chapter 7 Chapter 8 References Cited