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Revegetation of Upper Elevation Debris Slide Scars on Mount Le Conte in the Great Smoky Mountains National Park

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I am submitting herewith a thesis written by Susan Meta Feldkamp entitled "Revegetation of Upper Elevation Debris Slide Scars on Mount Le Conte in the Great Smoky Mountains National Park." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Botany.

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REVEGETATION OF UPPER ELEVATION DEBRIS SLIDE SCARS ON MOUNT LE CONTE IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

A Thesis
Presented for the
Master of Science
Degree
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Susan Meta Feldkamp

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ABSTRACT

Vegetation and environmental data from nine debris slides on Mt. Le Conte were analyzed in this study. Ages of the debris slides ranged from 1.5 to about 50 years at the time of sampling in the summer of 1980. Vegetation was sampled using 50 cm x 50 cm plots along horizontal transects across each slide. Data collected in each plot included the percent cover of each vascular plant species as well as depth to impenetrable obstruction, bare rock cover, bryophyte cover and lichen cover.

Debris slides were divided into vertical zones and horizontal zones based upon slide shape, slope angle and profile in cross-section. The first of the three vertical zones studied was the the head zone at the top of the slide; the next lowest zone was the erosion-transportation zone; the lowest zone studied was the next one, the transportation-gully zone. A terminal zone, the deposition zone, was located below the transportation-gully zone but was not studied. Two horizontal zones, a center and margin at each lateral edge, were recognized.

The effects of time on debris slide recovery and revegetation were noted. With increasing age, soil depth increased, bare rock cover decreased, and cover of vascular plants, bryophytes, and lichens increased on most parts of each debris slide.

Different trends in vegetation composition were noted among plots of the horizontal and vertical zones and among slides of different ages. Some species, such as Carex misera, were more frequent in the head zone rather than in the other two zones, while others, such as Saxifraga michauxii, occurred throughout. Individuals of certain species, for example, Carex misera, appeared with greater frequencies in young slides; other taxa, for example, Calamagrostis cainii, were found established only in older slides. Forbs and graminoids were the life forms occurring most frequently. Trees and shrubs were present less frequently in younger slides; numbers of individuals and cover increased from younger to older slides.

Analysis of variance indicated significant differences among vertical zones and horizontal zones as well as among slide age classes. Data used were mean values of depth to rooting obstruction, bare rock cover, bryophyte cover and lichen cover.

Seven community types were separated at the 45 percent dispersion level using cluster analysis. Three of these types, the Saxifraga michauxii type, the mixed herb type, and the Carex misera type were found in young slides and highly disturbed areas of somewhat older slides. Four community types, the Solidago glomerata type, the Diervilla sessilifolia type, the Rubus canadensis type, and the *Calamagrostis cainii* type, were found only in recovering, older slides.

Debris slides are dynamic areas subject to ongoing natural disturbance. Successful colonizers appear to be stress-tolerant species able to withstand recurrent disturbance. Several rare vascular plant species, such as *Gentiana linearis*, *Krigia montana*, and *Calamagrostis cainii*, which require non-forest sites at high elevations were found in these debris slides.

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CHAPTER I

INTRODUCTION

Large debris slides are a prominent feature of the south face of Mt. Le Conte in the Great Smoky Mountains National Park. These debris slides support several unique plant communities found only in these steep, open areas.

The vegetation of these debris slides has been described only briefly and in general terms. Bogucki (1970) provided descriptions and vegetation lists for those debris slides which formed during a heavy rainstorm on September 1, 1951. Crandall (1958) briefly mentioned the vegetation of rocky slopes below Myrtle Point and Cliff Top on Mt. Le Conte.

The topography of the upper elevations of Mt. Le Conte is distinguished by steep valleys with sharp ridges and pinnacles, a landscape with many areas of sufficient slope angle for debris slide formation. The majority of slides have south-facing aspects. All of the debris slides share topographic and climatic similarities yet show differences in microhabitat within an individual slide. Debris slide age also greatly influences the extent of revegetation and community composition. Thus these debris slides present an interesting high elevation example of recovery and revegetation over time after severe disturbance.

Field work for this study was performed in the summer of 1980. The objectives of this study were to describe debris slide vegetation, to relate the pattern of the vegetation to slide topography and to note the consequences of time on the composition of the vegetation. In addition, the effects of age and other environmental factors on variables other than vascular plant composition were examined. These objectives were met by plot sampling of vegetation and other variables followed by the use of multivariate numerical techniques to reveal patterns of habitat choice by the vegetation.

Many of the plant species growing within debris slides are dependent upon the continuing advent of open, disturbed habitat. Several of these taxa are listed as threatened or endangered in Tennessee and/or the U.S. The present research would assist in management of debris slide areas by providing knowledge of the pattern of colonization of these species and their habitat.

CHAPTER II

REVIEW OF SELECTED LITERATURE

Definition and Description of Debris Slides

Debris slides and related forms of mass movement have been the subject of extensive studies by geographers and geologists. However, few detailed examinations of vegetation before and after debris slide disturbance have been published.

The terms "mass movement" and "mass wasting" refer to the movement of material on slopes as a direct result of gravity without significant contributions from transporting agents such as streams, waves, glaciers, or wind (Bogucki 1970). Categorizing the many types of mass movement phenomena is difficult, for individual mass movements may be transitional in nature between two basic types or a combination of types. In 1938, C.F.S. Sharpe devised a well-respected classification system which used the kind and rate of movement, the relative water content, and the type of material involved as keys to distinguish between types of mass movement. A fundamental division separates mass movement phenomena into slides and flows.

Bogucki (1970) found that the mass movement phenomena in the Mt. Le Conte region revealed characteristics similar to both the "debris avalanche" and "debris slide" of Sharpe´s classification system, the former having a higher water content than the latter. He concluded that these mass movements intergraded from sliding (on the higher portions of the slide tracks) to flowage (on the lower segments) and chose the term "debris slide". The non-technical terms "landslide" or "slide" are frequently used for the larger, more rapid mass movements in which at least some movement of material in the solid state takes place.

Causes of debris slide formation are many and varied. Debris slide areas all exhibit considerable topographic relief, humidity sufficiently high enough to develop a thick cover of soil, and occasional torrential rainfalls. Rock structure may be a controlling factor as slide scars are typically found on bedrock surfaces which have joints or sheeting planes parallel to the slide track (Bogucki 1970). Stringfield and Smith (1956) found two primary causes of landslide formation in northeastern West Virginia after 12 to 16 inches of rain fell within twenty-four hours: the steepness of the affected slopes and the low permeability of the underlying bedrock (relatively impervious sandstone, quartzite and shale) which increased the speed and amount of runoff rather than allowing storm waters to enter the ground. Bogucki (1977) found that debris slides in the Adirondacks usually formed on slopes greater than 30 degrees and that the slide scar normally began a short distance downslope from the ridge crest.

During actual debris slide formation, Bogucki (1970) found that vegetation was almost entirely removed from the slide track by the slide material which consisted of rock, regolith, soil, forest litter and water. Deposition of this material usually occurred where large immovable objects such as trees or boulders were present on the outside bank of bends in the slide track or at a decrease in slope. Occasionally, an exceptionally large pile of tree trunks known as a log jam formed.

Geologic and Geographic Studies

Most studies of debris slides are concerned only with the geomorphological significance of the debris slide event with little examination of the subsequent revegetation. Many studies have described a typical debris slide pattern in which the slide is comprised of three or more longitudinal sections. Both geologic and vegetation studies of debris slides and similar earth movements often recognize a natural separation of a slide into several divisions.

In a study of landslides and their revegetation in the White Mountains of New Hampshire, Flaccus (1958) described the typical debris slide as being composed of three sections: a relatively wide and shallow upper part produced by sliding action, a narrower V-shaped gully cut through underlying till, and a stream scour section which often terminates in an already established drainage channel. A generalized diagram of a debris slide adapted from an idealized profile drawn by Flaccus is presented in Figure 1.

Bogucki (1970) studied debris slides resulting from a cloudburst over the Mt. Le Conte - Sugarland Mountain area in the Great Smoky Mountains National Park. Within one hour in the late afternoon on September 1, 1951, 4 - 6 inches of rain fell and more than 100 individual slides formed. He studied and mapped many of these in an effort to determine the nature of mass movement involved, the amount of material removed, and the diameter, aspect, and slope angle of each. All slides selected for study were within the Alum Cave Creek watershed located on the southwest slope of Mt. Le Conte. This area was near the site of maximum precipitation during the 1951 storm and contained slides at various elevations and on different slope exposures. The slides were divided into three sections: the scar head, the middle zone, and the area of deposition at the bottom.

Scott (1972) studied debris avalanches and their causes and contributing factors in the White Mountains. He divided these debris avalanches into four basic segments.

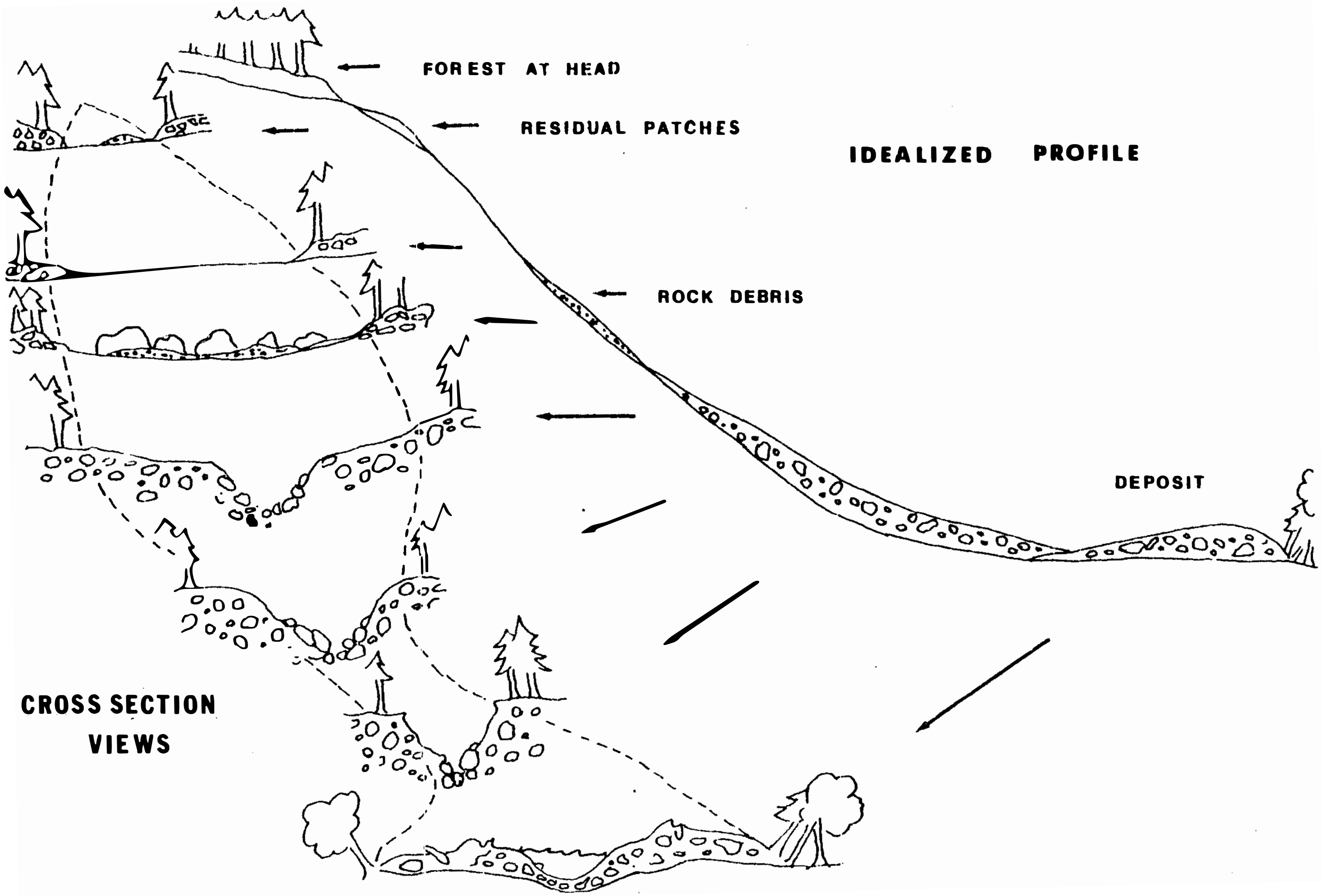


Figure 1. Idealized profile of debris slide (adapted from Flaccus 1958).

The uppermost portion, the erosional head section, is the widest portion of the slide and begins on a steep slope needed for slide initiation. In longer debris slides this section may be followed by an erosion-transportation section which begins as the slide narrows and consists of a winding, U-shaped trough scoured down to only slightly weathered bedrock in the center. The shortest segment of a debris slide, the transportation-gully section, occurs next. It begins at the break in slope between the erosional area and the depositional area as the slide becomes V-shaped in cross section. It includes a deep central gully exposing bedrock. A wide rim at each edge of this slide section retains a thin cover of soil but is denuded of vegetation. The debris slide terminates in a depositional area formed from deposited materials.

Vegetation Studies

Relatively few detailed studies have investigated revegetation in debris slides. Flaccus (1958) examined revegetation in a series of debris avalanches in the White Mountains of New Hampshire dating back to 1885. Five habitat types within these slides were described: bare cliffs and ledges, talus deposits at the foot of ledges and steep places, areas of erosion in glacial till, residual areas, and areas of deposition. Revegetation was very slow in the first two habitat types, moderately slow in the third, and comparatively rapid in the latter two types. Presence lists were compiled in 22 of the 29 slides visited, but quantitative vegetation sampling was conducted only in depositional areas. Early successional tree species invaded the more stable parts of the slide immediately after the disturbance, forming thickets within 10 years. The less stable ledges and talus deposits were vegetated largely by herbs, sedges, and grasses.

Langenheim (1956) studied plant succession on a subalpine earthflow in Colorado. The flow was divided into six major areas on the basis of physiographic differences. Plant communities appeared to be correlated with the relative stability of the substrate and the degree of soil development. Unstable areas were populated almost exclusively by only three herbaceous species. Langenheim described seven xeric community types and recognized three successional sequences occurring during the revegetation process.

Revegetation of the Mt. Le Conte debris slides studied by Bogucki (1970) was only briefly described and no attempt was made to quantitatively determine the community composition. Of the three slide segments, the depositional area was noted to have shown the greatest degree of revegetation, while the vegetation of the middle segment and scar head was described as "transitional" and "relatively sparse," respectively.

Scott (1972) found that revegetation in debris avalanches in the Blue Ridge Mountains occurred fastest in sites at lower elevations and latitudes. Vegetation returned most quickly to soil-covered slide portions (very few of these slides were completely stripped of soil during formation) and lower slide segments recovered fastest. The erosional head section and transportation-gully section recovered moderately rapidly; exposed bedrock areas were the last parts of the slide to revegetate.

Veblen et al. (1977) studied plant succession on fellfields (slopes consisting of unstable rubble) in timberline areas in the Andes of south-central Chile. The vegetation of these areas consisted primarily of herbs, bryophytes, and lichens capable of withstanding extreme instability and a variety of other environmental stresses.

Hull and Scott (1979, 1982) studied succession of woody species only on debris avalanches of Nelson County, Virginia, caused by Hurricane Camille in 1969. The major factors found to contribute to recovery rate and species composition were the amount of regolith removed during slide formation and the composition of the surrounding forest. They noted a lack of uniformity among revegetation of different debris slides due to differences in the forest composition surrounding the slide locations.

Garwood, Janos, and Brokaw (1979) examined the effects of earthquake-caused landslides on tropical forests in Panama and New Guinea and found that earthquake rates in the latter area are sufficiently high so that large areas of disturbed, nonclimax forest result.

Hupp (1981) studied the effects of small periodic rock slides on cove slope forests in block field areas of the central Appalachian region and found that the original forest composition was maintained after slope disturbance via seed germination as long as the magnitude of disturbance was relatively small. Hemlock and birch, the dominant tree species in the adjacent undisturbed forest, had their highest importance values during the first year, while pioneer species did not have high importance values until the second year after disturbance.

Debris slides have been noted along with fire, lightning, and other events, as a type of disturbance in many ecosystems. Bratton et al. (1979) discuss debris slides as an important type of disturbance among steep slopes at high elevations in Great Smoky Mountains Nation Park. The mid- and lower sections of slides may become forested in 50 to 500 years (depending on initial site condition) and old debris slide heads may develop into steep seepage meadows likely to be dominated by *Carex* and possibly supporting herbaceous plants not present in the surrounding forest.

Patterns of plant succession in open rock areas similar to the unstable, exposed bedrock portions of debris slides have frequently been described. Oosting and Anderson (1939) found that randomly located pioneer plants provided starting points for vegetation growth outward, forming mats of vascular plants in shallow depressions in granite rock in eastern North Carolina. McCune (1977) found similar patterns in the development of plant cover on a talus slope in western Montana. Succession began with establishment of a bryophyte mat in rock interstices; vascular plants then germinated and grew on this mat.

Daubenmire and Slipp (1943) described differences in plant succession on the north- and south-facing sides of a talus slope in northern Idaho. They found that the aridity of the south-facing slope slowed revegetation and limited it to marginal encroachment by vascular plants. Succession on the north slope, however, was more rapid and was initiated by bryophytes. Island-like thickets of mosses and vascular plants formed, eventually creating linear patterns of vegetation at right angles to contour lines.

The rocky slopes below Myrtle Point and Cliff Top on Mt. Le Conte were mentioned briefly by Crandall (1958) in her study of ground vegetation patterns of the spruce-fir area of the Great Smoky Mountains National Park. However, whether the sample areas visited were slide scars or other bedrock outcrops was not stated. The author noted scattered specimens of *Parnassia asarifolia* and patches of *Saxifraga michauxii* as well as clumps of sedges rooted in masses of *Sphagnum* spp. or in small pockets of soil.

CHAPTER III

THE STUDY AREA

Location and Relief

The Great Smoky Mountains lie along the border of North Carolina and Tennessee in the southern part of the Blue Ridge province of the Appalachian Highlands. Within the 780 square miles comprising the park there are 16 peaks whose elevations exceed 6000 feet; Mt. Le Conte, with an elevation of 6593 feet (2010 m), is the third highest. It is located ca. three miles northwest of the main crest of the Great Smoky Mountains. Although only about six miles southeast of Gatlinburg, Tennessee, the mountain´s summit rises more than a mile above the town. The area is characterized by extremely steep slopes and sharp ridge crests. The slopes of Mt. Le Conte itself contain a number of ridges radiating in various directions and separated by deep valleys. Mt. Le Conte is drained by several streams; Styx Branch, Trout Branch, and Alum Cave Creek are predominant streams on the south-facing side, the location of most of the debris slides included in this study. This topography is particularly susceptible to debris slide formation.

Geology

Bedrock geology. Most of the rocks of the study area consist of thick beds of metamorphosed sedimentary rock of late Precambrian age known as the Ocoee series. Within the study area, this appears primarily as coarse-bedded sandstone interbedded with slate, phyllite, and schist (Bogucki 1970). The Ocoee Series rests upon a basement complex of granite and metasedimentary gneiss. Although it is mostly sedimentary in origin, other rocks were intruded into the Ocoee Series at later times, producing sills and dikes, vein quartz, and granite gneiss in several locations (Bogucki 1970).

Two subdivisions within the Ocoee Series which contain related sequences are the Snowbird group and the Great Smoky group. The latter group is 10,000 feet (3048 m) to 15,000 feet (4572 m) thick in the eastern region of the Great Smoky Mountains National Park and is coarser and more varied in texture than the Snowbird group. Graded bedding and poor sorting characterize the rocks of this group. The Great Smoky Group contains two subgroups which are of importance within the debris slide area: the Thunderhead sandstone and the Anakeesta formation (Hadley and Goldsmith 1963).

The Thunderhead sandstone, the thickest and most widespread formation within the group, comprises much of the high crest of the range from Mt. Le Conte eastward. Underlying portions of the south slope of Mt. Le Conte, it consists of mostly sandstone and conglomerate, and includes gray slate, phyllite, quartz-mica schist, granite, and quartzite conglomerate. Because of its extensive inter-tonguing with both underlying and overlying formations, the Thunderhead sandstone varies considerably in thickness; it is estimated to be approximately 5,000 (1524 m) to 6,000 feet (1829 m) thick on the north slope of Mt. Le Conte (Hadley and Goldsmith 1963). Rugged topography and extensive cliff outcrops characterized this formation. In many places, it intergrades with the other important formation of the Great Smoky Group, the Anakeesta formation.

The Anakeesta formation is comprised of dark carbonaceous and sulfide-bearing rocks interspersed with thin dolomite beds. A considerable variety of other rocks is present, including conglomerates, graywacke, sandstone, argillites and gray and dark slates. Iron sulfide occurs in considerable quantities throughout. The formation crops out abundantly on the crest and on the southern slopes of Mt. Le Conte, an area with a large number of debris slides. Several exposures occur at points along the Alum Cave Bluffs trail between Alum Cave Creek and the summit and at Cliff Top and at Myrtle Point. Here, narrow and steep-sided ridges and craggy pinnacles, prominent features of the Anakeesta formation, are much in evidence. Residual soils of this formation are notably thin (Hadley and Goldsmith 1963).

Surficial geology. The slopes of the study area are mantled with colluvium and fresh or slightly weathered bedrock. Very little saprolite is present and alluvium is limited to the stream beds or stream edges at elevations below the study area. The colluvial material on slopes is loose and unconsolidated and usually derived from the underlying bedrock. Within debris slide areas, the depth of colluvium is generally inversely proportional to the steepness of the slope (Bogucki 1970).

Soils

The majority of forest soils at the higher elevations in the Great Smoky Mountains are Inceptisols belonging to the Umbric Dystochrept subgroup, according to the Seventh Approximation of the Soil Conservation Service classification (Wolfe 1967). Inceptisols are soils without development of eluvial or illuvial horizons and are classified into the great group Dystochrepts.

Soils within the study area result primarily from the in-place weathering of bedrock and residual materials. The Soil Survey of Sevier County, Tennessee (Hubbard et al. 1945) assigns these soils to the Ramsey series, a series which is developed on mountain slopes and ridge crests from the residuum of quartzite, sandstone, and conglomerate, or slate and fine-grained conglomerate.

Soils derived from the Anakeesta formation are referred to as Ramsey shaly silt loam. These soils are excessively drained and have low water-holding capacity (Hubbard et al. 1963). Bedrock outcrops are common and soil is shallower on the upper slopes.

Soils derived from the Thunderhead sandstone formation are termed Ramsey stony fine sandy loam. They are similar to those in the Anakeesta formation, forming from quartzite, sandstone, and conglomerate and having low water-holding capacity (Hubbard et al. 1963).

Climate

The high relief and rugged topography of the Great Smoky Mountains produce wide variations in local climate. The highest peaks of the Smokies are well-known for their mean annual high precipitation and low temperatures. With increasing elevation, the temperature decreases at an average rate of 4.0° C per each 1000 m rise (Shanks 1954). The study sites are all located within high elevation spruce-fir forests where spring and summer air temperatures are 5° to 8° C lower than the base of the mountains.

Yearly precipitation averages well over 203 cm in the spruce-fir zone (Whittaker 1956). The southern

Appalachian precipitation regime, with two maxima, one in winter or early spring and the other in midsummer, gives the Smokies their pattern of seasonal high rainfall. According to the Thornthwaite climatic classification system, the study area could be categorized as a rain forest (a microthermal perhumid) climate (Shanks 1954).

Flora and Vegetation

The known vascular flora of the Great Smoky Mountains consists of over 1,400 taxa (White 1982). The age of the area, its diversity of topography and, consequently, of habitat, and the variety of temperature and moisture conditions have combined to produce this extremely diverse flora.

One of the present forest communities prevalent in the study area is the spruce-fir forest. This unique vegetation type is dominant at elevations above 4,500 feet (1372 m) - 5,000 feet (1524 m) on Mt. Le Conte and is characterized by importance of *Picea rubens*, *Abies fraseri*, *Sorbus americana*, *Betula lutea*, and *Prunus pensylvanica*. In draws 4,500 feet (1372 m) - 5,800 feet (1768 m) the northern hardwood forest community type occurs. This is the uppermost extension of the mixed mesophytic forest (Whittaker 1956) and is dominated by *Betula lutea*, *Fagus grandifolia*, some *Acer saccharum* and *Aesculus octandra*. In addition, a variety of characteristic herb and shrub species occur in the forest understory and open clearings. *Oxalis montana*, *Athyrium asplenioides*, *Solidago glomerata*, *Impatiens pallida*, *Rubus canadensis*, and *Aster acuminatus* were found beneath the spruce-fir canopy and in open areas (Crandall 1958).

Vegetation communities of the high mountain region of the Southern Appalachian Mountain region were described by Ramseur (1960). Spruce-fir forest was present on several of the high peaks and ridges comprising the study area and reached its maximum development at elevations of about 6000 feet (1830 m). An extensive spruce-fir forest occurred in the Smokies, with *Sambucus pubens* and *Rubus canadensis* frequently present in slight canopy openings. Although Ramseur did not specifically describe the flora of debris slides nor similar disturbed areas, he discussed fire and logging as two kinds of disturbance that change community structure. Fire cherry, *Prunus pensylvanica*, played an important role as a dominant plant in a developmental series of six communities following fire. Other communities sampled included grass balds, heath balds, shrub balds, and beech forests.

CHAPTER IV

DATA COLLECTION AND PREPARATION

Field Methods

Nine slides were used in this study. All were chosen on the basis of their elevation, accessibility, aspect, slope angle, and age. Reconnaissance of Mt. Le Conte revealed that these nine slides could be reached on foot. Each of these slides was located in the elevation band of 5600 feet (1707 m) to approximately 6300 feet (1920 m). Slides were chosen which varied from about 1.5 to at least 50 years old at the time of the field data collection in the summer of 1980.

Slide selection was aided by interviews with hikers and employees of Le Conte Lodge and aerial photographs. In addition, maps drawn by Bogucki (1970) indicated locations of debris slides resulting from the 1951 rainstorm. Information regarding the dates of occurrence of the debris slides was gathered personally by correspondence and interviews with persons familiar with the area, from material at the National Park Service Archives at Sugarlands Visitors Center, and from aerial photographs taken by the Forest Service.

Each debris slide was divided on the basis of morphological characteristics into three vertical zones as suggested by Scott (1972): the head zone, the erosion-transportation zone, and the transportation-gully zone. An additional lower terminus dump zone occurs below these three zones, but this zone was at a much lower elevation and was not investigated. In addition, debris slides were divided laterally into horizontal zones: center and margins. The approximate width of each zone was measured using a rangefinder. Aspect was determined using a Silva Ranger compass. Slope angle was measured using a clinometer.

Horizontal transects were made at 15 m intervals across each zone of each slide and 50 X 50 cm plots were placed at 1 m intervals along each transect. Because of the often extreme slope angle and rough terrain, a collapsible sampling frame with adjustable legs was used. Leg adjustment levelled the frame which then consistently measured a horizontal 50 X 50 cm area. The number of plots taken in each zone was sufficient to yield a plateau in the vascular plant species/area curve (Goldsmith and Harrison 1976). The total number of plots was 521.

Several environmental data were recorded per plot: the approximate amount of soil moisture (using a subjective scale ranging from 1 = dry to 4 = submerged), the amount of canopy cover (ranging from 1 = open to 3 = shade) and the percent of the plot occupied by bare rock (bryophyte and lichen cover were excluded). In addition, the depth to impenetrable obstruction at the plot center was determined by inserting a ruled metal rod 1.2 cm wide into the substrate.

Biological data recorded in each plot were: cover by lichens (percent), cover by bryophytes (percent), and the cover of each vascular plant species (percent). If the latter were a tree or a shrub, the number of individuals (each single main stem was counted as one individual) was recorded. For vascular species with a cover equal to or greater than 5 percent, the depth to impenetrable obstruction at the largest clump of individuals was determined by inserting the metal rod into the soil at the base of the clump. The largest grouping of each species in the plot with cover greater than or equal to 5 percent was assigned to one of a series of microhabitat categories; these were rock crevice, soil, or bare rock.

Vascular plant and bryophyte collections were made from June, 1980 through September, 1980. The University of Tennessee vascular plant herbarium was used to aid in the identification of collected plant specimens. Vascular plant nomenclature follows that of Radford et. al. (1968). Bryophyte nomenclature is that of Conard and Redfearn (1979). Forty-four vascular plant species (Table 1) were found in the study area. Some of the common bryophytes and lichens were identified to the genus level only.

Table 1. Common and Scientific Names of Vascular Species and Corresponding Codes.

Code	Scientific Name	Common Name
ABSFRS	*Abies fraseri*	Fraser fir
AGSPRN	*Agrostis perennans*	Upland bent grass
ANGTRQ	*Angelica triquinata*	Filmy angelica
ASPMNT	*Asplenium montanum*	Mountain spleenwort
ASTACM	*Aster acuminatus*	Whorled wood aster
ASTDVR	*Aster divaricatus*	White wood aster
ATHASP	*Athyrium asplenioides*	Southern lady fern
BTLLUT	*Betula lutea*	Yellow birch
CCLRGL	*Cacalia rugelia*	Rugel´s ragwort
CLGCAN	*Calamagrostis cainii*	Cain´s reed-bent grass
CRXCRN	*Carex crinita*	Drooping sedge
CRXDBL	*Carex debilis*	Necklace sedge
CRXMSR	*Carex misera*	Miserable sedge
CRXRDT	*Carex radiata*	Radiate sedge
CLNLYN	*Chelone lyonii*	Pink turtlehead
CNNLTF	*Cinna latifolia*	Woodreed
DTHCMP	*Danthonia compressa*	Mountain oat grass
DNNPNC	*Dennstaedtia punctilobula*	Hayscented fern
DRVSSS	*Diervilla sessilifolia*	Sessile-leaved bush honeysuckle
DRPINT	*Dryopteris intermedia*	Intermediate woodfern
EPTRGS	*Eupatorium rugosum*	White snakeroot
GNTLNR	*Gentiana linearis*	Linear-leaved gentian
GLYNBG	*Glyceria nubigena*	Smoky mountain mannagrass
HSTSRP	*Houstonia serpyllifolia*	Thyme-leaved bluets
HYPGRV	*Hypericum graveolens*	Mountain St. John´s-wort
IMPPLL	*Impatiens pallida*	Pale touch-me-not
KRGMNT	*Krigia montana*	Mountain krigia
LPHBXF	*Leiophyllum buxifolium*	Sand myrtle
LXLECH	*Luzula echinata*	Wood-rush
MNZPLS	*Menziesia pilosa*	Minniebush
OXLMNT	*Oxalis montana*	Wood sorrell
PARASR	*Parnassia asarifolia*	Grass-of-Parnassus
PICRBN	*Picea rubens*	Red spruce
PRNPNS	*Prunus pensylvanica*	Fire cherry
RHDCTW	*Rhododendron catawbiense*	Catawba rhododendron

Table 1 (Continued)

Code	Scientific Name	Common Name
RHDMNS	*Rhododendron minus*	Small-leaved rhododendron
RBSCND	*Rubus canadensis*	Smooth blackberry
SMBPBN	*Sambucus pubens*	Red-berried elder
SXFMCH	*Saxifraga michauxii*	Michaux´s saxifrage
SCRCSP	*Scirpus cespitosus*	Deerhair bulrush
SLDGLM	*Solidago glomerata*	Skunk goldenrod
SRBAMR	*Sorbus americana*	American mountain-ash
VCCERY	*Vaccinium erythrocarpum*	Mountain cranberrybush
VIOMCL	*Viola macloskeyi*	Northern white violet

Computer Methods

Vegetation and environmental data collected during sampling were recorded in the field on specially modified FORTRAN sheets and were keypunched by the University of Tennessee keypunching staff. Computer analysis was performed using the IBM 360 and the DEC-10 Model 1080 computers at the University of Tennessee. The Statistical Analysis System (SAS) (Barr et al. 1976) was used for all data organization procedures and most descriptive statistics and analyses. Numerical classification was performed using CLUSTR, a program written by Post and Shepard (1974) containing algorithms equivalent to Orloci´s (1967) clustering procedures.

CHAPTER V

SLIDE DESCRIPTIONS

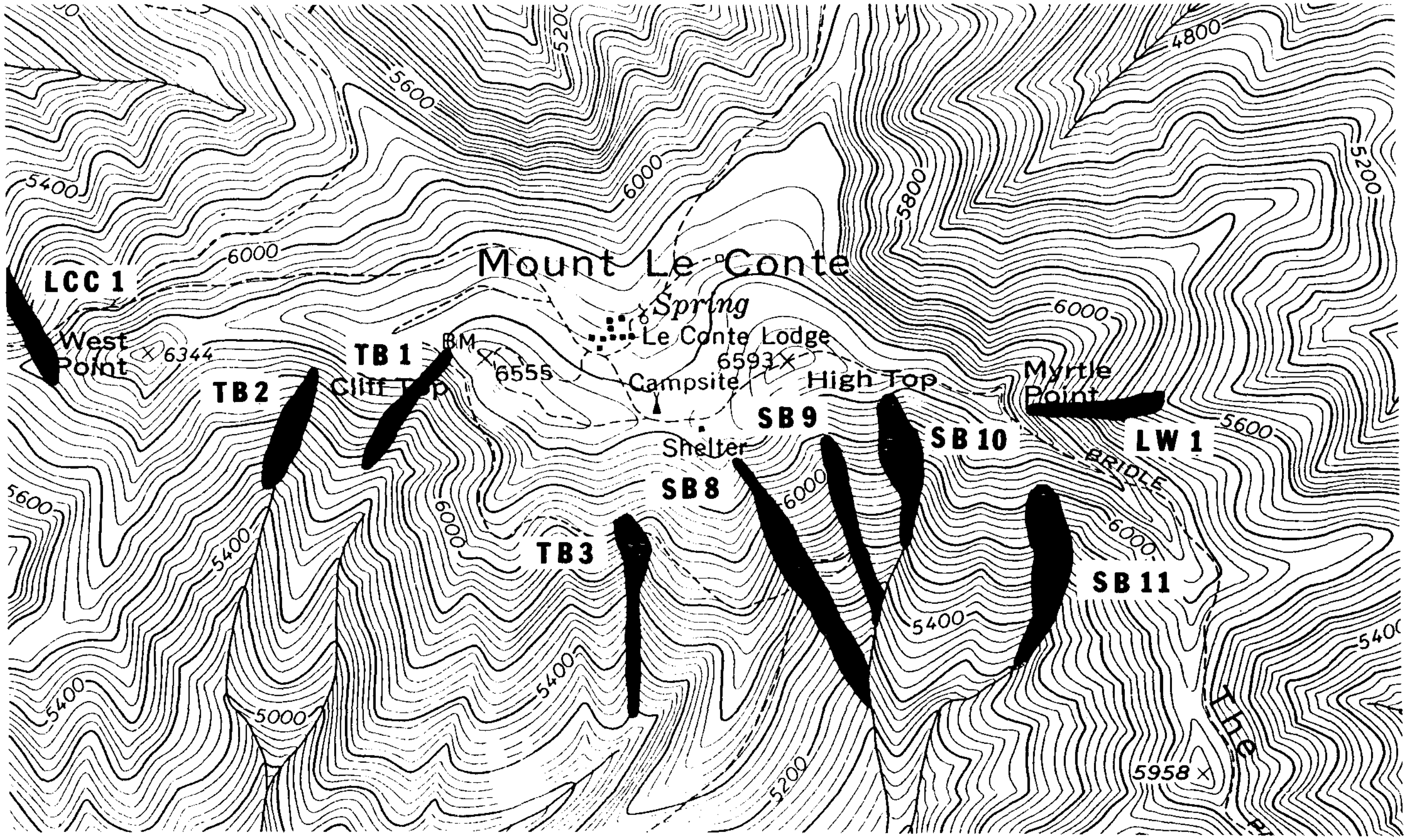
Introduction

The summit of Mt. Le Conte consists of four small peaks; from west to east, these are West Point, Cliff Top, High Point, and Myrtle Point. The debris slides included in this study initiate below the crests of these peaks (Figure 2).

Nine debris slides were included in this study (Table 2). Five were described by Bogucki (1970). Four of these, SB-8, SB-9, SB-10, and SB-11, lie within the Styx Branch River drainage, and a fifth, TB-3, lies within the Trout Branch drainage. Bogucki´s nomenclature has been retained for these slides.

Four other debris slides formed after Bogucki´s study were also sampled. These slides included LCC-1, in the Le Conte Creek drainage, TB-1 and TB-2, both within the Trout Branch drainage, and LW-1, lying within the Lowes Creek drainage.

Eight of the nine slides are located on the Anakeesta Formation, according to a geologic map of Great Smoky Mountains National Park and vicinity (King et al. 1968). The only north-facing slide, LCC-1, is underlain by the Thunderhead Sandstone formation.



SCALE 1:12750   1" = 0.20 miles

Figure 2. Summit of Mt. Le Conte study area with debris slides (in black) (base from U.S.G.S. Mt. Le Conte 7.5 minute quadrangle map).

Table 2. Debris Slides on Mt. Le Conte.

Name (Abbreviation)	Aspect	Age (Years)[a]	Mean Slope Angle (Percent)	Total Number of Plots
TB-1	SW	1.3	65	85
SB-11	S	4	70	73
TB-2	SW	10	70	72
LCC-1[b]	N	10	70	46
LW-1[c]	NE	10	80	24
SB-8	S	29	70	77
SB-9[b]	S	29	70	25
SB-10	S	29	70	65
TB-3	S	50+	75	55

[a]Age in 1980 at the time of sampling.

[b]Two vertical zones sampled.

[c]One vertical zone sampled.

Individual Debris Slide Descriptions

SB-8. This south-southeast-facing 29-year-old debris slide ranged in width from 14 m at the head zone to 30 m at the widest point of the erosion-transportation zone. The erosion-transportation zone is intersected twice by the Alum Cave Bluffs Trail at elevations of approximately 5560 feet (1695 m) and 5580 feet (1701 m).

With a slope of 80 percent, the head zone is the steepest section of the slide. Loose slate fragments dissected by shallow water runoff channels comprised the head zone substrate. Moisture appeared to remain consistently high in the area and *Gentiana linearis*, *Calamagrostis cainii*, and *Solidago glomerata* flourished in the open center. Large numbers of *Prunus pensylvanica* ranging from 9 to 12 m in height were interspersed with *Diervilla sessilifolia*, *Vaccinium erythrocarpum*, and *Rubus canadensis*, with *Athyrium asplenioides* lining the margin. The head zone terminated upslope in a 12 - 16 m cliff.

The erosion-transportation zone is intersected twice by the Alum Cave Bluffs Trail. At its upper end, exposed bedrock in the slide center was evident. This open center almost always contained flowing water and the center was repeatedly scoured during heavy rainstorms witnessed by the author. An irregular pattern of bedrock ledges and outcrops and occasional boulders created a step-like terrain with grasses and sedges in rock niches in the 60 percent slope. Dense populations of *Saxifraga michauxii* and bryophytes grew in the center. Several clumps of *Scirpus cespitosus* and *Glyceria nubigena* occurred in this zone. Marginal dense stands of *Diervilla sessilifolia*, *Rubus canadensis*, and *Vaccinium erythrocarpum*, with 3 to 6 m tall individuals of *Betula lutea* occurred. *Leiophyllum buxifolium* and *Menziesia pilosa*, two shrubs seen only on older debris slides, grew here. Vegetation "islands" of these shrubs (with *Betula*) have formed throughout the lower two zones, a pattern consistent among debris slides of advanced age.

Vegetation of the transportation-gully zone consisted primarily of a closed canopy of *Betula lutea* and *Prunus pensylvanica* 3 to 6 m high. Gullies between rock outcrops persist at the slide edge.

SB-9. A sharp bend in the Alum Cave Bluffs trail borders the western edge of the lower end of SB-9, thus affording easy access to this south-facing debris slide. The slope angle (70 percent) and elevation of the sampled portions of this 29-year-old slide were similar to that of slide SB-8, its western neighbor.

The head zone, visible when approached from the crest, was extremely steep. Vegetation sampling was not possible in the slide head due to the substrate instability and the sharp cliff approximately 16 m beyond the point of slide initiation (i.e., the upper end of the head zone). Exposed bedrock was covered with a layer of loose slate fragments. Vegetation cover was sparse and was limited to Carex spp. and Saxifraga michauxii. The erosion-transportation zone was slightly concave in cross-section and approximately 30 m wide. The slide center was occupied by large boulders and outcrops and was vegetated by extensive stands of Saxifraga michauxii. At least some water flowed through this zone throughout the season of observation.

The transportation-gully zone was sharply V-shaped in cross section, narrower than the zone above, and filled with boulders at the upper end. "Slump" of marginal soil materials appeared to be an important factor in the revegetation process, aiding the inward movement of trees and shrubs from the margin to the center. A distinct marginal community of Rubus canadensis, Diervilla sessilifolia, and Rhododendron spp. covered the steep banks of this gully-like area in addition to such shade-tolerant herbs as Athyrium asplenioides and Oxalis montana.

SB-10. The upper edge of this 29-year-old debris slide head was over 100 m below the west end of Myrtle Point and was visible from the trail between High Point and

Myrtle Point. Forbs and graminoids were the most abundant vegetation life forms.

The head zone, approximately 18 m wide, was covered with slate fragments and was well vegetated with low shrubs and heliophytic forbs such as Solidago glomerata and Chelone lyonii. Few boulders or rocky ledges were present. As a consequence of the lack of open rock substrate and considerable degree of revegetation, Saxifraga michauxii occurred infrequently. Several individuals of Prunus pensylvanica approximately 6 m in height as well as Sorbus americana occurred in the margins.

In the erosion-transportation zone, the slide widened but was not yet concave in cross section. Several small water troughs fanned outward along the slide between outcrops and boulders. Many large clumps of Scirpus cespitosus grew on the western edge of this zone. Carex crinita, a sedge found only in older debris slides, occurred in drier places throughout the slide. The slide widened to approximately 30 m and flattened sharply to a broad expanse of bedrock. Small rivulets were present and small individuals of Prunus pensylvanica grew in interstices between boulders. A stream up to 2 m wide along the eastern edge moved through boulders to the transportation-gully zone which assumed a sharply westward bend. Here, SB-10 joined the terminus of a smaller, uninvestigated slide entering from the east.

SB-11. First formed in 1951, this south-facing debris slide was greatly expanded during a rainstorm in 1976. This slide lies in a valley east of the southwest-extending ridge below Myrtle Point. From its steep, broad head of exposed bedrock to its endpoint in a massive logjam at the head of the Styx Branch River, the slide reaches nearly 1500 feet in vertical extent and is nearly half a mile (805 m) in length (John Carpenter, verbal communication). In length and width, it was the largest of the debris slides on Mt. Le Conte.

The head zone dropped sharply away from a spruce-fir forest perimeter and its colluvium consisted of dark gray to black slate and other material weathering in place and producing large loose fragments. The resultant extreme instability of substrate resulted in a depauperate flora in the 70 percent slope of the head zone. *Saxifraga michauxii*, *Carex debilis*, and *Carex crinita* were plants with frequencies above 5 percent. The vascular forbs and graminoids appeared wilted and under high transpiration stress during each visit to the site. The fine-textured soil forming from the weathering of underlying bedrock apparently had low water-holding capacity. Some *Rubus canadensis* seedlings were seen, but all were under 25 cm and several were stunted. There was no evidence in the form of water channels of runoff from higher elevations. The wide stands of shrubs and small deciduous trees seen in other debris slide margins were lacking here. Only a few Picea rubens and Abies fraseri seedlings were visible at the slide edges.

Boulders and irregular rock outcrops with niches more suitable to vascular plant growth marked the upper end of the erosion-transportation zone. Here, the slide was less steep and became somewhat concave in cross section. Ledges of 1 - 2 m in height were frequent.

TB-3. This south-facing debris slide was the oldest of the slides sampled on Mt. Le Conte. Dr. Aaron J. Sharp remembered this slide from his first hikes up the Alum Cave Bluffs Trail in 1924 (personal communication). The slide was bisected below the head by the Alum Cave Bluffs Trail.

With its meadow-like appearance, this debris slide was strikingly different from its younger counterparts. Little exposed bedrock remained. Generally, vegetation covered all areas except boulders and steep-sloped outcrops which were without soil and thus devoid of vascular plant cover. The extensive degree of revegetation coupled with a soil layer relatively thick (mean soil depth to obstruction at plot center = 5.0 cm) when compared to all other debris slides sampled supported the advanced age of this slide.

The head zone of this slide was approximately 23 m wide and had a slope of 75 percent. It was covered with a dense growth of _Calamagrostis cainii_ and _Carex misera_ interspersed with frequent clumps of _Gentiana linearis_, _Krigia montana_, and _Parnassia asarifolia_. The area was continuously wet.

Exposed bedrock and boulders became more evident in the erosion-transportation zone. _Calamagrostis cainii_, _Carex misera_, _Saxifraga michauxii_ and _Gentiana linearis_ remained the major elements of the vegetation.

The upper end of the transportation-gully zone became a V-shaped trough. _Rubus canadensis_, _Diervilla sessilifolia_ and _Vaccinium erythrocarpum_ had high frequency and cover on the margins and seemed to be encroaching on the open center.

LCC-1. This debris slide lay along the Bull Head trail approximately 3/4 mile west of Le Conte Lodge in the Le Conte Creek drainage. It was one of two debris slides in the study area with a generally northerly aspect and was the only one facing almost directly north. From information gathered from members of the Le Conte Lodge staff, the slide was estimated to be under 10 years of age. Its mean slope angle of 70 percent was the same as or similar to that of the other debris slides.

The uppermost part of the slide was below the western edge of the crest of the main ridge of Mt. Le Conte. The head zone consisted of a steep, sheer, bedrock cliff and was inaccessible to sampling.

The erosion-transportation zone included a central water channel. Extremely large boulders (approximately 3 cubic m) and exposed bedrock comprised the major elements of the vegetation habitat. A sharp cliff occurred at the eastern margin of the slide. The site appeared consistently moist and was wetter than any other debris slide. Extensive mats of _Sphagnum_ sp. as deep as 30 cm were noted in the margins. This site had the largest populations of the mesophyte _Chelone lyonii_ of all debris slides sampled.

The transportation-gully zone was atypical of that seen in other debris slides. The lowermost third of this debris slide was broad and level, lacking a central water channel. Little exposed bedrock was visible, as the area was covered with _Betula lutea_ and _Rubus canadensis_ between 1 and 2 m in height, and _Diervilla sessilifolia_ and _Chelone lyonii_.

_TB-1_. This debris slide formed during the third week of March, 1979, and was the youngest slide sampled. The mean slope angle of 65 percent was very similar to that of the other slides sampled. The upper end of the slide is at the Alum Cave Bluffs Trail several meters east of the wooden gate on the Alum Cave Bluffs Trail atop Mt. Le Conte. From Cliff Top all but the lower portion of this southwest-facing slide was easily visible.

At the time of sampling, little revegetation had occurred, particularly in the head zone. This portion of the debris slide was distinguished by broad expanses of bedrock and surface slate fragments. Clumps of Saxifraga michauxii and Carex misera and young Prunus pensylvanica and Rubus canadensis individuals, none over 30 cm in height, comprised the only significant vegetation. Residual soil at the slide edges supported Diervilla sessilifolia and Sphagnum sp. Water channels approximately 30 cm deep and 30 cm wide had their origin in the center of the head. These were devoid of bryophytes, perhaps due to the young age of the slide. Along its eastern edge, the head region abutted a cliff at the base of which a stream of water ran continuously.

The slide narrowed into the erosion-transportation zone. Many conifers had fallen into the slide but had decayed little. In the transportation-gully zone, the slide narrowed to a width of about 12 m and attained the characteristic V-shaped cross section. Its steeply banked margins of open soil were vegetated by small individuals of Rubus canadensis and Diervilla sessilifolia.

LW-1. This small debris slide with a northeastern aspect lay in the Lowes Creek drainage; its head lay below a section of the Boulevard Trail approximately 0.5 mile east of Le Conte Lodge. The age of this slide was estimated to be somewhat less than 10 years. Only the erosion-transportation zone of this slide was sampled, as the extreme steepness of the head zone prohibited secure footing and a high chute-like cliff at the base of the erosion-transportation zone made access to the transportation-gully zone impossible.

The erosion-transportation zone of this slide was extremely disturbed and showed little sign of post-slide recovery. On the steep 80 percent slope, the slaty rock fragmented and continually moved downslope. As a result, an extremely small number of species occurred at this site. *Saxifraga michauxii*, *Carex radiata*, and *Carex misera* were the only species of greater than 5 percent frequency.

TB-2. This debris slide lies off the western ridge of Mt. Le Conte and has a southwestern aspect. Its age was estimated to be under 10 years. It may be reached by leaving the Alum Cave Bluffs Trail at the wooden gate and walking west along a formerly used trail to West Point approximately one-eighth of a mile from Le Conte Lodge. Lying in a narrow valley, the slide could be seen from a vantage point at the Chimney Tops but was hidden from view from all perspectives along the Alum Cave Trail.

The slide head lay about 60 m below the crest of the ridge just below a steep spruce-fir forest slope. The head was surrounded by much fallen timber and was too steep to obtain adequate footing in several places. The area was fairly moist. *Chelone lyonii* occurred frequently among the irregular bedrock outcroppings in the slide head.

A narrow water trough on the ledges of exposed bedrock was a major feature of the transportation-gully zone. The debris slide was edged with *Saxifraga michauxii*, *Carex* spp., and *Rubus canadensis*. At the lower portion of this zone, the slide edges were very steep and were covered primarily with bryophytes and ferns such as *Athyrium asplenioides*. Below the area sampled, the western edge of the slide widened, becoming a broad expanse of open bedrock approximately 15 m wide. Another small stream entered the debris slide channel here from the west.

Summary

The nine debris slides sampled represented a unique variety of high elevation habitats available to those species suited to these open, rocky areas. Although these areas were of different sizes, ages, and aspects, they were marked by many fundamental similarities.

All debris slides studied initiated below the crest of a steep (60 percent or greater) slope. In all cases, the slope angle appeared to be less on the crest itself than in the head region and the distance from crest to the upper end of the slide may serve as a catchment for the quantity of rainfall necessary to initiate slide formation. Seven of the nine debris slides face generally south and slide formation may be due to the steepness of Mt. Le Conte´s southern face and the inclination of the mountain´s Anakeesta shale cap (Bogucki 1970).

All of the debris slides consisted of three basic vertical zones. These seem to be typical of debris slides wherever they occur. Flaccus (1958) and Scott (1972) each described vertical zones occurring in a downhill sequence in slides of the White Mountains and Blue Ridge Mountains, respectively. Each also noted the presence of horizontal zones extending lengthwise through the slide.

Vertical zonation. The head zone, similar in appearance among all sites, formed a rounded apex that widened as it lengthened approaching the erosion-transportation zone. This zone had been scoured to bedrock, with all boulders and debris removed at the time of slide formation. Soil genesis was slow and began with the weathering in place of fragmented bedrock. Scar heads on all except the oldest slides appeared continually very dry and showed little evidence of water runoff or seepage. Among the younger slides this stringent environment supported hardy heliophytes such as Carex misera, Carex debilis, and Saxifraga michauxii.

The erosion-transportation zone was the widest section of any of the slides sampled. The slope angle was less than that of the head but ranged from 65 to 80 per cent. This zone was shallowly U-shaped in cross-section, narrowing and deepening downslope toward the transportation-gully zone. Even among the older slides, bedrock remained exposed in one or more central water runoff channels. Boulders and rock outcrops collected soil on their upslope sides and thus served as centers of vegetation "islands" projecting above the open debris slide. A distinct marginal flora in the form of dense stands of vascular plants at the lateral edges of the slide was noted in all sites. The trees, shrubs, and forbs growing here required the greater depth of rooting medium found in a slide margin but lacking in a center where exposed bedrock predominates and water flow quickly removes organic material. The debris slide center was dominated by heliophytic forbs and graminoids able to thrive in extremely shallow soils and to withstand flooding.

The transportation-gully zone was the narrowest and generally the least steep of the three slide zones. It was distinguished by its sharply V-shaped cross-section. The steep banks at the edges of this zone were covered by soil material and were often devoid of plant cover in younger slides because soil was continually washed away. A water channel across the bare rock bedrock in the center generally remained regardless of the slide age. Small trees and shrubs comprised the largest fraction of the vegetation. This zone had the highest mean shrub cover while mean graminoid cover was lowest here. Canopy cover was densest in this slide section and species needing high light intensities occurred infrequently. Fallen trees, rocks, and other examples of debris resulting from the slide formation event were present.

Horizontal zonation. Vegetation and environmental variables were distinctly different between debris slide centers and margins. This horizontal zonation was most apparent in the erosion-transportation and transportation-gully zones and less so in the steep but flattened head zones.

The slide center included the lowest point of the debris slide in cross-section. Exposed bedrock with water channels extending between rock outcrops predominated in these areas. During heavy rainstorms, a heavy flow of water rushed down the center forming one or more deep channels while removing soil and rock particles. Hence, soil depth was extremely low in debris slide centers.

Vegetation was thus generally sparse in slide centers, due to repeated flooding and the paucity of soil. Vascular plants with the highest frequency were those which were able to root successfully in cracks in the bedrock and between boulders. Depending upon the width of the debris slide, canopy cover was usually low and heliophytes dominated the debris slide center. Plants characteristic of seepage areas occurred here frequently.

Debris slide margins extended from the shoulders of the central depression of the slide to the slide edges where the slide met undisturbed surroundings. Soil of considerable thickness may be present here due to slumping after slide formation. This effect was most pronounced in the erosion-transportation and transportation-gully zones. The slide margins remained consistently moist because of the amount of soil cover and lateral seepage and shading.

Because of the proximity of the undisturbed spruce-fir forest, canopy cover was greater in the margins than in the center, and the flora consisted primarily of shrubs and forbs of the open forest.

CHAPTER VI

VEGETATION DATA AND ABIOTIC DATA

Vascular Plants

Slide age, aspect, slope angle, and the location of a plot within the slide were all important factors in determining the extent of vegetation cover and its composition. The slides showed a range of degree of both non-vascular and vascular plant cover. Because of the extreme patchiness of the habitat, debris slide vegetation was a network of loosely-knit plant stands. Although slide age was an obvious factor in the progress of revegetation, the characteristics of the substrate in the horizontal or vertical zone usually determined the degree and kind of revegetation. Comparisons between debris slides were therefore difficult and conclusions concerning the extent of post-disturbance recovery in each site were limited.

Slide centers showed trends in vegetation composition different from those seen in slide margins. Some vascular species did not appear to be habitat specific, colonizing all portions of the debris slide equally; others seemed to prefer slide centers or margins.

Several of the species appearing with high frequency displayed one of these patterns of colonization. *Saxifraga michauxii*, *Carex misera*, and *Carex debilis*, three species found in greatest numbers on younger slides, were ubiquitous in both centers and margins and showed equal or nearly equal frequencies in each. The frequencies of Krigia montana, Calamagrostis cainii, and Gentiana linearis were two to four times greater in the slide centers than in the margins. These species are dependent upon recurring disturbance for the high light intensity which they apparently require. Diervilla sessilifolia, Viola macloskeyi, and Oxalis montana, elements of the spruce-fir understory community, occurred 2 to 19 times more frequently in the margin than in the center. This is probably due to the proximity of the margins to the adjacent undisturbed spruce-fir habitat where shade, seed sources, deeper soil, and a constant moisture source were available.

Different debris slides had different taxa appearing with high frequency (Table 3). The number and the percent cover of early successional species (particularly forbs and graminoids) declined in older slides while some other forbs and shrubs increased in frequency and cover. In sites 29 to 50+ years of age, Saxifraga michauxii and Carex debilis had frequencies only one-fourth to one-third those in TB-1, the youngest slide. The frequency of Calmagrostis cainii increased with slide age; it was absent from TB-1, appeared with intermediate frequencies in slightly older slides, and had a mean

Table 3. Frequency of Vascular Taxa in Debris Slides Sampled.

Species / Slide, Age (Years)	TB-1 1.3	SB-11 4	TB-2 10	LW-1 10	LCC-1 10	SB-8 29	SB-9 29	SB-10 29	TB-3 50+
Abies fraseri	2.4	2.7	1.4	1.3	2.2	3.9		3.1	7.3
Agrostis perennans			2.7			2.6	8.0	9.2	
Angelica triquinata			2.7			3.9		1.2	
Asplenium montanum	7.0	2.7	21.0		1.3		2.4		
Aster acuminatus	4.7	23.3	12.5		34.7	40.2	12.0	30.7	18.1
Aster divaricatus			1.4						
Athyrium asplenioides	3.5	13.7	4.2		13.0	1.3	12.0	1.5	3.6
Betula lutea		4.1	2.8		4.3	1.3		1.5	1.8
Cacalia rugelia			1.4			6.5	4.0		
Calamagrostis cainii						41.6	4.0	26.2	72.7
Carex crinita		5.5						4.6	3.6
Carex debilis	43.5	34.2	19.4		6.5	18.1	12.0	12.3	12.7
Carex misera	23.4	45.2	23.6	29.1	6.5	14.3	4.0	26.2	49.3
Carex radiata				16.7	41.3				
Chelone lyonii	2.4		16.7		30.5	6.5		27.7	1.8
Cinna latifolia			4.2			1.3		7.7	
Danthonia compressa						16.9			
Dennstaedtia punctilobula						6.5		1.5	
Diervilla sessilifolia	17.6	4.1	16.7		13.0	27.2	12.0	36.9	3.6
Dryopteris intermedia			1.4					3.1	
Eupatorium rugosum		16.4	4.2			2.6	28.0	26.1	
Gentiana linearis						12.9		24.6	34.5

Table 3 (Continued)

Species / Slide: Age (Years)	TB-1: 1.3	SB-11: 4	TB-2: 10	LW-1: 10	LCC-1: 10	SB-8: 29	SB-9: 29	SB-10: 29	TB-3: 50+
Glyceria nubigena						10.3		1.5	1.8
Houstonia serpyllifolia		1.4	2.7			28.6	8.0	53.8	16.3
Hypericum graveolens	3.5	6.8	6.9			23.4	4.0	18.5	18.2
Impatiens pallida			11.1			1.3	24.0	1.5	
Krigia montana						31.2		23.0	10.9
Leiophyllum buxifolium						1.5	1.5		
Luzula echinata							12.0		
Menziesia pilosa		8.2	2.7	4.2	6.5	3.9		1.5	
Oxalis montana	14.1	1.4	18.0	4.2	21.7		28.0	1.5	
Parnassia asarifolia		1.4	3.1		4.3				
Picea rubens	2.4	1.4				2.6		1.5	
Prunus pensylvanica	5.9	1.4	7.3	4.2	6.5				
Rhododendron catawbiense			1.4						1.8
Rhododendron minus		1.4			2.2	2.6			7.3
Rubus canadensis	34.1	32.9	26.4		23.9	24.7	32.0	12.3	23.6
Sambucus pubens	1.2		4.2						
Saxifraga michauxii	60.0	63.0	77.8	95.8	76.1	33.8	72.0	32.3	14.5
Scirpus cespitosus						1.3			
Solidago glomerata	5.9	21.9	2.8		2.2	40.0	16.0	32.3	18.2
Sorbus americana	1.2		5.6	4.2	4.3	1.3		1.5	1.8
Vaccinium erythrocarpum		2.7	1.4		4.3	3.9		1.5	9.1
Viola macloskeyi	18.8	42.5	26.4		45.7	46.8	52.0	33.8	29.1

frequency of 72 percent in TB-3, the oldest slide. *Viola macloskeyi*, *Aster acuminatus*, *Solidago glomerata*, and *Diervilla sessilifolia* increased in frequency in all older slides except in TB-3, a slide dominated by graminoids. The increase in frequency of tree species through time was very slow. *Abies fraseri*, for example, had a mean frequency of 2 percent in TB-1, the youngest slide, and a mean frequency of only 7 percent in TB-3, the oldest slide.

Because the three vertical zones of the debris slides recover at different rates, the location (with reference to the headwall) of a plot was important in determining the species composition as well as the number of individuals (density) and cover of each species.

Debris slide heads are the steepest of the three zones and typically consist of exposed bedrock without boulders or similar niches to facilitate species invasion. Within the heads of slides included in this study pieces of slate, phyllite, and quartz-mica schist had weathered off boulders and headwalls and moved downslope, further impeding plant establishment in the heads in the paths of these moving rocks.

The lower two zones of the debris slides had reached more advanced stages of revegetation. Erosion-transportation zones, which were less steep than head zones and were littered with cobbles and boulders, could retain both material from above as well as soil slump material moving into the slides from the margins. Transportation-gully zones were flanked by steep soil banks slumping into this V-shaped section of the slide from the undisturbed forest along the margin

Measurements of the depth to impenetrable obstruction were determined for each taxon with a cover greater than or equal to 5 percent in each plot (Table 4). Species with high frequencies and high covers in young debris slides (for example, Saxifraga michauxii and Carex debilis) had low mean depths to obstruction. Diervilla sessilifolia, Oxalis montana, and Rubus canadensis, species which occurred throughout older slides and in the more successionally advanced margins of debris slides of median age, exhibited higher mean depths to obstruction.

The proportion of all plots which lacked vascular plants (Table 5) was used as an additional way by which to gauge the extent of revegetation of each slide. Within the six completely sampled slides, the largest percentage of plots without vascular plant cover occurred in TB-1, the youngest slide, and the smallest percentage in TB-3, the oldest slide. Plots devoid of vascular taxa in TB-1 had depths to obstruction ranging from 0 cm to 8 cm and percent bare rock ranged from 0 to 100 (higher figures indicated boulders or ledges). Within TB-3, however, each of the two

Table 4. Mean Soil Depths (cm) Available for Rooting of Vascular Taxa.

Species	N	Mean	S.D.
Abies fraseri	13	17.5	11.4
Agrostis perennans	5	5.2	2.5
Angelica triquinata	8	4.5	2.2
Asplenium montanum	6	7.2	3.2
Aster acuminatus	65	5.3	4.1
Athyrium asplenioides	25	9.6	8.5
Betula lutea	5	6.6	9.9
Cacalia rugelia	5	6.6	4.2
Calamagrostis cainii	73	6.2	4.5
Carex crinita	8	8.3	6.9
Carex debilis	70	5.4	3.1
Carex misera	94	5.9	4.4
Carex radiata	14	6.9	4.9
Chelone lyonii	29	6.3	4.9
Danthonia compressa	10	5.2	3.4
Dennstaedtia punctilobula	6	5.5	2.2
Diervilla sessilifolia	55	7.5	4.5
Dryopteris intermedia	2	12.5	6.4
Eupatorium rugosum	29	8.5	4.7
Gentiana linearis	29	6.2	3.6
Glyceria nubigena	9	8.1	4.8
Houstonia serpyllifolia	40	6.0	4.5
Hypericum graveolens	28	6.6	3.9
Impatiens pallida	5	8.8	5.1
Krigia montana	21	3.3	1.9
Luzula echinata	1	6.0	
Menziesia pilosa	2	14.0	15.6
Oxalis montana	22	12.0	8.6
Parnassia asarifolia	1	5.0	
Picea rubens	5	13.0	1.9
Prunus pensylvanica	6	11.3	5.6
Rhododendron catawbiense	2	6.0	0.0
Rhododendron minus	4	8.3	2.1
Rubus canadensis	100	6.9	4.8
Sambucus pubens	4	9.8	7.4
Saxifraga michauxii	153	4.3	3.2
Solidago glomerata	76	6.7	4.1
Sorbus americana	3	10.7	5.7
Vaccinium erythrocarpum	8	10.3	10.4
Viola macloskeyi	52	5.9	3.8

Table 5. Extent of Vascular and Non-Vascular Plant Cover in Debris Slides.

Variable / Slide / Age (Years)	TB-1 1.3	SB-11 4	TB-2 10	LW-1 10	LCC-1 10	SB-8 29	SB-9 29	SB-10 29	TB-3 50+
Depth to obstruction ($\bar{x}$ cm/plot)	4.4 (5.5)[a]	3.6 (4.1)	4.5 (4.1)	3.6 (6.6)	3.9 (6.2)	4.1 (4.2)	2.1 (3.0)	3.6 (4.4)	5.0 (5.1)
Bare rock ($\bar{x}$ percent/plot)	20.3 (29.7)	28.8 (37.5)	20.3 (34.0)	24.7 (31.5)	25.9 (31.7)	19.2 (30.9)	37.6 (36.8)	20.4 (30.6)	10.9 (21.5)
Plots with no vascular plants (percent)	14.1	10.9	6.9	0	4.5	3.9	16.0	6.2	3.6
Total no. vascular taxa/slide	18	22	33	8	21	34	20	34	24
Vascular taxa ($\bar{x}$ number/plot)	2.5 (1.9)	3.7 (2.3)	3.3 (2.6)	1.7 (1.0)	3.6 (2.2)	4.6 (2.3)	3.8 (3.0)	4.8 (2.3)	3.7 (2.2)
Total vascular cover (mean percent/plot)	19.9 (4.8)	37.0 (7.6)	33.8 (6.7)	22.3 (22.1)	40.7 (8.6)	60.5 (7.7)	33.3 (32.0)	57.9 (15.6)	51.2 (20.0)
Bryophyte cover (mean percent/plot)	5.1 (5.9)	3.2 (7.7)	5.2 (1.4)	20.3 (25.5)	21.0 (19.9)	8.4 (9.4)	10.8 (15.3)	5.7 (5.6)	8.3 (10.9)
Lichen cover (mean percent/plot)	0.8 (1.6)	1.8 (2.2)	0.5 (1.4)	3.3 (3.2)	4.0 (2.6)	2.8 (3.7)	4.4 (2.9)	3.7 (3.6)	3.6 (3.1)

[a] Standard deviation.

plots without vascular plants had a depth to obstruction of 0 cm and the bare rock percentage was 90.

Vascular species were grouped into one of four life form categories: tree, shrub, forb, or graminoid. Fifty-eight percent of the observed species within all of the sites were forbs, 22 percent were graminoids, 13 percent were shrubs, and 6 percent were trees (the remaining 2 percent of the plots lacked vascular plants). Forbs and graminoids appeared in the highest percentages in slides of median age, those slides which were in an intermediate stage of recovery (Table 6). Shrubs and trees both constituted a high percentage of observations in TB-1, the youngest site, but their frequency decreased in all older slides, except for TB-3, which shows a slight upward rise in both shrub and tree frequency. This suggests that many of the woody plants which first appear in a young slide do not survive, while graminoids and forbs better adapted for the harsh environment, do survive.

Life form frequencies also showed noticeable patterns among vertical zones on slides. Forb frequency within a slide increased moving downslope, while graminoid frequency simultaneously declined. Tree and shrub frequency were highest in the transportation-gully zone.

Canopy cover (1 = open, 2 = intermediate, 3 = shade) had a mean value of 1.0 in slide centers and 1.6 in

Table 6. Frequency and Mean Cover of Life Forms in Debris Slides.

Slide	Aspect	(Years)[a]	Frequency/$\bar{x}$ Cover of Life Forms			
			Tree	Shrub	Forb	Graminoid
TB-1	SW	1.3	15.2/13.5	37.6/ 9.8	74.1/14.1	54.1/ 7.1
SB-11	S	4	12.3/ 7.6	41.0/21.9	84.9/18.1	60.2/20.5
TB-2	SW	10	23.6/13.6	33.3/11.6	90.2/25.8	41.6/ 7.7
LW-1[b]	NE	10	16.6/15.5	0.1/ 4.0	95.8/15.3	41.6/ 9.5
LCC-1[c]	N	10	21.7/ 7.6	39.1/32.0	91.3/26.6	52.1/ 9.1
SB-8	S	29	16.8/20.4	41.5/33.8	92.9/30.6	74.0/18.5
SB-9[c]	S	29	20.6/ 7.6	31.0/25.2	72.4/24.1	34.4/ 5.3
SB-10	S	29	15.3/24.5	43.0/30.1	92.3/33.4	66.1/16.0
TB-3	S	50+	25.4/12.0	34.5/35.0	63.6/ 9.0	87.2/26.6

[a]Age in 1980 at the time of sampling.

[b]One vertical zone sampled.

[c]Two vertical zones sampled.

margins. Using a scale of moisture conditions (1 = dry, 2 = moist, 3 = wet, 4 = submerged), the great majority of plots were found to be moist.

Bryophytes and Lichens

Bryophyte species found included both drought-resistant species in areas of high light intensity as well as those which require more moist habitats. *Andreaea* typically occurred in exposed, dry, rocky areas. Crum (1976) noted that bryophytes such as *Andreaea* may precede lichens as pioneers on bare rock. *Marsupella* spp., *Scapania* spp., and *Sphagnum* spp. grew mainly in shaded, wet habitats. Cain and Sharp (1938) found these species to be among those growing on rocks under *Abies fraseri* at upper elevations of Mt. Le Conte. *Dicranum* spp. and *Atrichum* spp. were bryophytes commonly found in the high elevation forest understory and occurred in slide margins.

The majority of the lichens commonly seen on the slides were of the crustose growth habit. Fruticose lichens such as *Cladonia* were seen in older slides.

Bryophyte cover appeared to be related to slide age and aspect. Mean bryophyte cover of each of the nine debris slides ranged from 3.2 to 21 percent. Mean percent bryophyte cover increased very slightly with slide age. Slide aspect appeared to have a greater influence on bryophyte cover than slide age. The two north-facing debris slides had bryophyte cover two to three times greater than that of the seven other south-facing debris slides.

Variations in mean bryophyte cover were also observed within each slide. Bryophyte cover in each of the lower two debris slide zones was approximately double that of the head zones; it was also approximately two times higher in slide margins than in centers throughout the length of a slide.

Lichen cover was low throughout all plots, ranging from zero to an infrequent high of 15 percent. The mean lichen cover per plot among all slides was 2.1 percent, indicating that the lichen contribution to community structure in these areas was negligible. Lichens tend to be far more widespread in disturbed habitats after bryophytes and some vascular plants have become established (Topham 1977).

Abiotic Data

Bare rock coverage decreased with increasing slide age. Plots of debris slide centers had a mean cover of bare rock of 31.7 percent; those of the margin, 7.9 percent. Within the three horizontal zones, head zones had the greatest mean cover of bare rock.

Measurement of the depth to obstruction at each plot center revealed that plots of debris slide margins (where slumping of soil may occur after slide formation) were deeper (mean = 6.2 cm) than those of debris slide centers (mean = 2.5 cm) where erosion continues in transient water courses forming during and after rainstorms. The mean values calculated for depth to obstruction at plot center and depth to obstruction at species clusters with percent covers of 5 percent or greater were 3.9 cm and 6.0 cm, respectively.

CHAPTER VII

ANALYSIS OF VARIANCE

Introduction

Analysis of variance was used in this study to examine relationships between the factors slide age and the horizontal zone and vertical zone of each plot and several environmental variables measured in each plot. Analysis of variance (abbreviated "anova") acts as a test of whether two or more sample means could have been obtained from populations with the same parametric mean with respect to one or more given variables (Sokal and Rohlf 1969). In biological research, it can be used to establish that two or more populations or samples are indeed different if means of one or more variables are judged to be different among populations by means of statistical significance tests. Analysis of variance permits the user to test for the existence of added treatment effects--that is, whether a group of means can simply be considered random samples from the same population or whether treatments which have affected each group separately have resulted in shifting these means sufficiently so that they can no longer be considered samples from the same population (Sokal and Rohlf 1969). A "treatment" may be an actual experimental manipulation or it may be some environmental difference not produced by the experimenter. The F-test is used as a significance test to detect the added component of variation due to treatment effects.

In the anova performed in this study, the different treatments were slide age and horizontal zone (center or margin) and vertical zone (head, erosion-transportation, and transportation-gully). In addition, variation among the individual slides within each age class was examined. Analysis of variance was used to attempt to find significant differences among horizontal and vertical zones as well as among different age classes on the basis of significant differences among means of four variables. Analysis of variance made possible the measurement of the effect of each treatment on each of the four measured response variables independent of the compounding effects of all other treatments.

Methods and Results

Analysis of variance was performed using the SAS program (Barr et al. 1976). Two abiotic variables, soil depth at plot center and percent bare rock, and two biological variables, percent bryophyte cover and percent lichen cover, were chosen for use as response variables in this analysis. Values of these variables were obtained in every plot. These variables were chosen because they were important indicators in assessing the extent of post-slide revegetation.

To make it possible to investigate the effects of age on the debris slide environment, slides were grouped into four age classes: 1.5 years, 4-10 years, 29 years, and 50+ years. Only plots of the six completely sampled debris slides were included in the analysis. Plots from the three slides which included one or more inaccessible vertical zones were excluded because they would not accurately represent a complete debris slide.

In performing any analysis of variance, certain underlying assumptions must be met. If one or more of these assumptions are violated, data may be transformed by one of several methods so that the resulting transformed variates will then meet the assumptions. In this study, graphical analysis of residuals in the model revealed that the subgroup means were positively correlated to the variances, a violation of the assumption of homogeneity of variances (i.e., the variances of all sample groups must be equal). Data were logarithmically transformed using common logarithms to reduce variance heteroscedasticity (inequality of variances among samples) and to produce a variance independent of the mean. The data were later back-transformed to the familiar arithmetic scale for use in comparing means among subgroups.

For each of the four variables included in the analysis, the null hypothesis stated that there were no significant differences among the mean values of that variable among plots of slides of different age classes or of different vertical zones or horizontal zones. Another way to state this is that the variance among treatments (in this case, age classes or vertical zones or horizontal zones) is less than or equal to the variance within treatments. Thus, the null hypothesis for any given combination of variable and treatment in this study would, if accepted, indicate that there is no significant difference between values of that variable in slides of different ages or among different horizontal or vertical zones and that the treatments being compared cannot therefore be assumed to be statistically different from one another. The null hypothesis would be rejected for any combination in which the variance of the response variable differed significantly among the treatments.

Depth to obstruction at plot center. The depth to obstruction at plot center varied with age class, horizontal zone, and vertical zone at significance levels of 5 percent ($P = 0.05$) or less (Table 7). It should not be surprising to find that these three factors had a significant effect on soil depth. Soil depth increases with the age of the slide. The horizontal zone in which a plot

Table 7. Analysis of Variance of Depth to Obstruction at Plot Center.

Source of Variation	df	M.S.	F Value
Total	426		
Age class	3	1.99	2.97*
Horizontal zone	1	46.68	69.61***
Vertical zone (age class x area)	12	1.68	2.51**
Age class x horizontal zone	3	0.27	0.40
Area x age class	2	0.20	0.30
Area x horizontal zone (age class)	2	0.87	1.30
Vertical zone x horizontal zone (age class x area)	12	1.19	1.78*
Other interactions involving area	391		

*significantly different at P = .05
**significantly different at P = .01
***significantly different at P = .001

is located influenced the degree of soil accumulation and was found to be highly significant. Plots in the margins of all slides had deeper soil than those of slide centers. Among the three vertical zones, soil accumulation tended to be most extensive in transportation-gully zones, less so in the erosion-transportation zones and head zones, respectively. In addition, a small amount of variance among remaining debris slides remained and was significant even after all other effects and interactions were removed. This remaining variance can be explained as the amount of natural variation inherently present among different slides.

Bare rock. The bare rock percentage varied with age class, horizontal zone, and vertical zone at a significance level of 5 percent ($P = 0.05$) or less (Table 8). Again, horizontal zone was found to be highly significant. Debris slide centers tend to maintain their open character and are revegetated more slowly than margins. Differences among age classes occurred due to the role played by time in vegetation encroachment on bare rock areas. Vertical zones tend to show decreasing percentages of bare rock as one moves downward from the head zone to the erosion-transportation zone to the transportation-gully zone. Because of the natural variations present among all of the debris slides, significant differences among

Table 8. Analysis of Variance of Bare Rock Percentage.

Source of Variation	df	M.S.	F Value
Total	426		
Age class	3	8.52	4.04*
Horizontal zone	1	143.14	67.94***
Vertical zone (age class x area)	12	10.34	4.91***
Age class x horizontal zone	3	2.22	1.06
Area x age class	2	0.35	0.17
Area x horizontal zone (age class)	2	0.47	0.22
Vertical zone x horizontal zone (age class x area)	12	5.18	2.46**
Other interactions involving area	391		

*significantly different at P = .05
**significantly different at P = .01
***significantly different at P = .001

individual slides remained after the removal of other effects.

Bryophyte cover. The bryophyte cover varied with age class, horizontal position and vertical zone at significance levels of 1 percent (P = 0.01) or less (Table 9). Bryophyte cover increased with the age of the slide and also tended to be higher in the moister, shadier margins than in the open centers. With regard to vertical zonation, percent bryophyte cover was higher in erosion-transportation zones and transportation-gully zones than in the open, exposed head zones. In addition, a significant portion of the variance in bryophyte cover may be attributed to variation of debris slides within the separate age classes.

Lichen cover. The percent lichen cover varied with age class and vertical zone at significance levels of 1 percent (P = 0.01) or less (Table 10). In addition, a significant portion of the variance in lichen cover may be attributed to variation between different slides and to debris slides nested within age classes. Significant interaction also occurred between the factors age class and horizontal zone. A comparison of the least squares means between the eight data set subdivisions representing the

Table 9. Analysis of Variance of Bryophyte Cover Percentage.

Source of Variation	df	M.S.	F Value
Total	426		
Age class	3	8.52	12.69***
Horizontal zone	1	14.51	21.59***
Vertical zone (age class x area)	12	1.71	2.55**
Age class x horizontal zone	3	1.01	1.51
Area x age class	2	2.81	4.19*
Area x horizontal zone (age class)	2	1.29	1.91
Vertical zone x horizontal zone (age class x area)	12	1.30	1.93*
Other interactions involving area	391		

*significantly different at P = .05
**significantly different at P = .01
***significantly different at P = .001

Table 10. Analysis of Variance of Lichen Cover Percentage.

Source of Variation	df	M.S.	F Value
Total	426		
Age class	3	8.27	16.71***
Horizontal zone	1	1.26	2.55
Vertical zone (age class x area)	12	1.84	3.72***
Age class x horizontal zone	3	3.74	7.55***
Area x age class	2	3.02	6.11**
Area x horizontal zone (age class)	2	1.04	2.10
Vertical zone x horizontal zone (age class x area)	12	0.99	2.00*
Other interactions involving area	391		

*significantly different at P = .05
**significantly different at P = .01
***significantly different at P = .001

interaction between age classes and horizontal zone revealed a trend of lichen cover two to three times higher in the margins of young slides than in the centers, a pattern which was then seen, in reverse, in the older slides. Because lichen colonization tends to occur after the earlier establishment of some bryophytes and vascular plants, lichens thus seemed to favor such semi-revegetated areas with intermediate cover such as young slide margins and older slide centers.

Although the debris slides in this study show many individual differences, these analyses of variance seem to support the separation of debris slides into both vertical and horizontal zones. This is supported both by site and ecological data. The age of the slide has a statistically significant effect on several of the variables examined here as well.

CHAPTER VIII

CLASSIFICATION AND DESCRIPTION OF COMMUNITY TYPES

Introduction

A major goal of this study was the classification of debris slide vegetation into communities. Orloci´s (1967) sum of squares method, one of a variety of numerical classification techniques known as cluster analysis, was selected to classify the plots. This is a hierarchical, agglomerative technique which creates clusters by minimizing the variance within groups while maximizing the variance between groups (Goodall 1978). The procedure operates by creating pairs of cases (in this study, plots) and calculating the within-group sums of squares for each. Those combinations yielding the least increase in the within-group sum of squares are retained. This process continues until all samples are combined into a single group. The program used in this analysis (CLUSTR, written by Post and Shepard, 1974) produces a dendrogram with levels which represent the within-group mean squares expressed as a percentage of the sample mean squares. The level of the increasing percent dispersion at which groups are identified is decided upon by the user.

The classification of this data set is based on the cluster analysis of total percent cover of the vascular plant species in each plot. A slide which had had each of the three zones sampled was selected from each of the four age classes. The 253 plots used in this analysis were those of slides TB-1, SB-11, SB-10, and TB-3.

The dendrogram produced by the program illustrates the grouping process at increasing levels of percent dispersion (Figure 3). Each plot was labeled with a code indicating its debris slide of origin and its horizontal and vertical location within the slide. No significant "runs" of plots from within one slide or one horizontal or vertical zone were observed with the exception of one community type which occurred exclusively in slide centers.

The 45 percent dispersion level, indicating that 55 percent of the total variance in the data was between-group variance and 45 percent was within-group variance, was chosen as the point at which to separate plant communities. This level was chosen because seven groups were well-separated at the 45 percent level and are easily recognized in the field. No communities dominated by trees fell out at this level because all of the tree species found in the slides occurred with very low frequency and cover. These seven groups are discussed as the community types considered here (Figure 3).

The frequency and mean percent cover of all species within each of the seven community types within the four

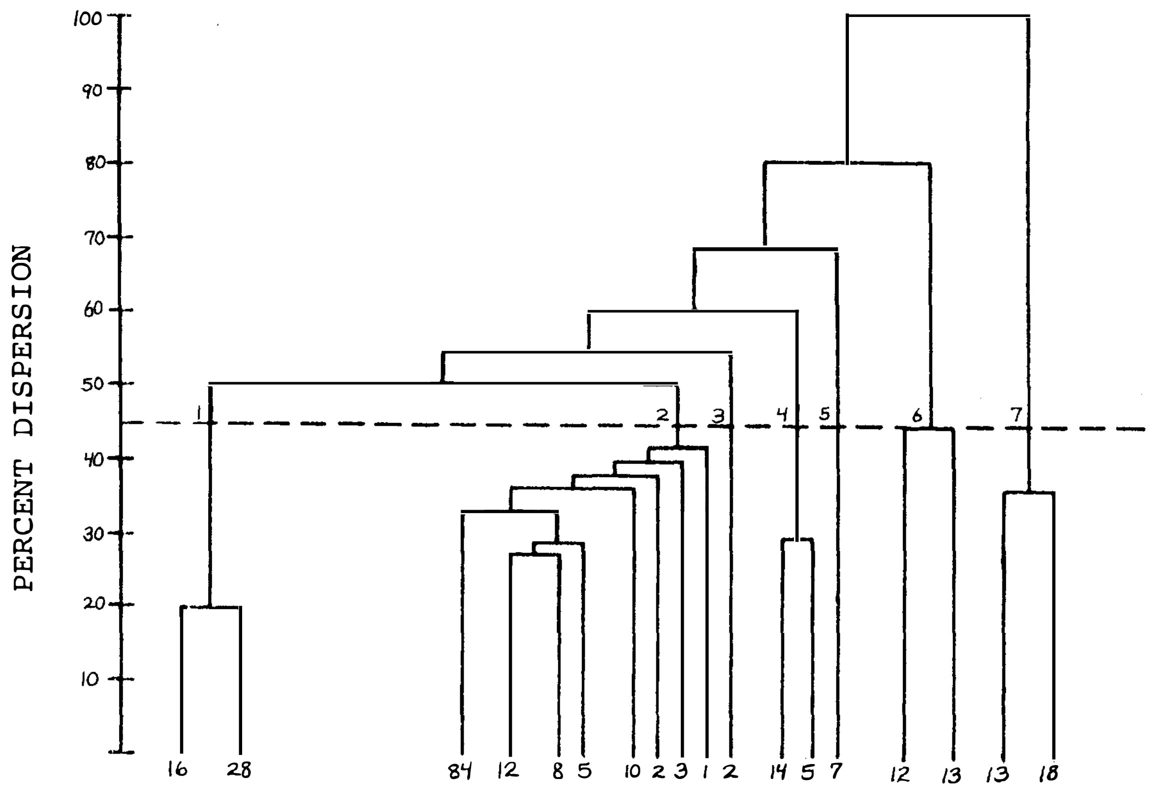


Figure 3. Dendrogram of cluster analysis of debris slide vegetation. Communities are defined at the 45 percent dispersion level, 1=*Saxifraga michauxii* (Michaux's saxifrage), 2=mixed herb, 3=*Solidago glomerata* (skunk goldenrod), 4=*Carex misera* (miserable sedge), 5=*Diervilla sessilifolia* (sessile-leaved bush honeysuckle), 6=*Rubus canadensis* (smooth blackberry), 7=*Calamagrostis cainii* (Cain's reed-bent grass).

debris slides are given in the table accompanying each community type description. Each table also includes the mean depth to obstruction and the mean percent bare rock per plot.

Saxifraga michauxii Type (N=44)

The *Saxifraga michauxii* type (Table 11) occurred throughout all of the debris slides except TB-3 (an old debris slide dominated by graminoids) and was found primarily in the debris slide centers. *Saxifraga michauxii* was the dominant species with a minimum cover of 15 percent. *Carex misera* and *Carex debilis* were codominant species and *Rubus canadensis* was a frequent associate species. Other vascular species in this community type were those of highly disturbed areas. *Saxifraga michauxii* grows vigorously in recently disturbed, highly stressed areas with little or no other vegetation. This type had the shallowest depth to obstruction (3.9 cm) and a high mean bare rock percentage of 21.4.

Mixed Herb Type (N=125)

Fifty percent of all plots in the analysis had vegetation of low cover and high diversity. No single taxon was prominent in plots of this community type (Table 12). These plots were from slides or slide subsections in which disturbance was fairly recent and the species diversity was fairly high. This community type had a bare

Table 11. Composition of the *Saxifraga michauxii* Type (N=44).

Species	Frequency	Mean Cover (Percent)	S.D.
Abies fraseri	2.3	4.0	
Asplenium montanum	4.5	4.0	0
Aster acuminatus	9.1	4.3	0.5
Calamagrostis cainii	2.3	5.0	
Carex debilis	40.1	6.7	3.6
Carex misera	40.1	4.7	1.4
Chelone lyonii	4.5	4.0	0
Diervilla sessilifolia	11.4	4.2	0.4
Eupatorium rugosum	9.1	4.5	0.6
Houstonia serpyllifolia	4.5	7.0	4.2
Hypericum graveolens	4.5	4.0	0
Prunus pensylvanica	2.3	5.0	
Rubus canadensis	20.4	5.6	2.6
Saxifraga michauxii	100.0	16.6	8.0
Viola macloskeyi	27.3	4.2	0.4
Mean depth (cm)	3.95		2.8
Mean bare rock (percent)	21.36		27.9

Table 12. Composition of the Mixed Herb Type (N=125).

Species	Frequency	Mean Cover (Percent)	S.D.
Abies fraseri	3.2	37.3	31.6
Agrostis perennans	3.2	4.0	0
Angelica triquinata	4.8	10.6	11.3
Asplenium montanum	0.8	4.0	
Aster acuminatus	16.8	5.1	2.1
Athyrium asplenioides	3.2	16.3	16.5
Betula lutea	3.2	20.8	32.8
Calamagrostis cainii	15.2	7.3	3.7
Carex crinita	3.2	15.0	10.8
Carex debilis	26.4	6.4	3.7
Carex misera	26.4	7.7	6.2
Chelone lyonii	5.6	10.9	13.5
Cinna latifolia	2.4	6.3	3.2
Diervilla sessilifolia	20.0	12.7	10.6
Eupatorium rugosum	14.4	10.9	8.7
Gentiana linearis	8.0	6.2	2.7
Glyceria nubigena	0.8	5.0	
Houstonia serpyllifolia	9.2	10.5	11.0
Hypericum graveolens	14.4	6.8	3.4
Impatiens pallida	0.8	5.0	
Krigia montana	12.8	7.3	5.2
Menziesia pilosa	3.2	4.0	0
Oxalis montana	4.8	8.7	7.0
Parnassia asarifolia	0.8	5.0	
Picea rubens	2.4	7.7	6.4
Prunus pensylvanica	2.4	4.3	0.6
Pyrus americana	1.6	4.0	0
Rhododendron minus	1.6	47.0	60.8
Rubus canadensis	17.6	6.3	3.3
Saxifraga michauxii	45.6	4.4	0.5
Solidago glomerata	15.2	14.3	9.4
Vaccinium erythrocarpum	1.6	17.0	18.4
Viola macloskeyi	24.0	4.8	1.8
Mean depth (cm)	4.87		4.6
Mean bare rock (percent)	22.00		30.7

rock percentage of 22, the highest value of this variable among all community types. The mean depth to obstruction was 4.9 cm.

Early successional species such as *Saxifraga michauxii*, *Carex misera*, and *Carex debilis* had the highest frequencies in this community. An additional 30 of the total 44 debris slides species appeared in this community type; these had low frequencies and low cover. No species had a cover greater than 20 percent except *Abies* and *Rhododendron* which had low frequencies. The herbaceous taxa in this community type were small in size and were successful in barren areas where soil had not yet formed and drought conditions prevailed except during rainfall events. Young seedlings of woody species such as *Rubus canadensis* and *Vaccinium erythrocarpum* occurred in these plots infrequently.

Solidago glomerata Type (N=2)

Two plots were distinct at the 45 percent dispersion level forming this community type (Table 13) due to very high cover of *Solidago glomerata*, an herb which is common in high elevation disturbed areas with high light conditions and sufficient moisture. The mean depth to obstruction is this type was 4.9 cm and the mean bare rock percentage was zero. *Solidago glomerata* also appeared with high frequencies in the *Diervilla sessilifolia* community type and in the *Rubus canadensis* community type. Ramseur

Table 13. Composition of the *Solidago glomerata* Type (N=2).

Species	Frequency	Mean Cover (Percent)	S.D.
Agrostis perennans	50.0	5.0	
Aster acuminatus	50.0	4.0	
Calamagrostis cainii	50.0	10.0	
Carex misera	100.0	4.0	0
Chelone lyonii	50.0	5.0	
Diervilla sessilifolia	50.0	20.0	
Rubus canadensis	50.0	10.0	
Solidago glomerata	100.0	82.5	10.6
Viola mackoskeyi	50.0	4.0	
Mean depth (cm)	4.87		4.6
Mean bare rock (percent)	22.00		30.7

(1960) noted an abundance of *Solidago glomerata* in a heath-weed community type found quite some time after fire disturbance on exposed ridges at high elevations in the Southern Appalachians. *Solidago glomerata* was found by Crandall (1958) at very high elevations on Mt. Le Conte among open forest areas composed of Fraser fir with sparse reproduction.

Carex misera Type (N=19)

Carex misera was noted throughout the study as a common vascular plant in highly unstable sections of older debris slides. In this community type (Table 14), *Carex misera* had a mean cover of 34 percent. *Asplenium montanum*, *Viola macloskeyi*, and *Rubus canadensis* were important associated species. Values of 11.6 calculated for mean bare rock percentage and 4.5 cm for depth to obstruction were intermediate among all slides.

Diervilla sessilifolia Type (N=7)

Diervilla sessilifolia, a shrub common in high elevation forest openings, was the dominant in this community type (Table 15). The type is one which showed the importance of encroachment by the flora of slide margins where residual soil is present and species requiring both soil and a steady moisture supply grow. Important associate species included *Eupatorium rugosum* and *Solidago glomerata*, species common in forest openings at

Table 14. Composition of the *Carex misera* Type (N=19).

Species	Frequency	Mean Cover (Percent)	S.D.
Asplenium montanum	47.4	6.7	4.0
Athyrium asplenioides	36.8	12.7	7.8
Betula lutea	5.3	30.0	
Calamagrostis cainii	10.5	10.0	7.1
Carex debilis	31.6	7.5	2.7
Carex misera	100.0	34.0	16.2
Diervilla sessilifolia	5.3	10.0	
Gentiana linearis	15.8	11.7	2.9
Houstonia serpyllifolia	15.8	4.3	5.8
Hypericum graveolens	5.3	4.0	
Menziesia pilosa	15.8	4.0	0
Oxalis montana	5.3	4.0	
Prunus pensylvanica	5.3	30.0	
Rhododendron catawbiense	5.3	30.0	
Rubus canadensis	47.4	15.0	8.7
Saxifraga michauxii	68.4	5.2	3.0
Solidago glomerata	31.6	5.7	2.2
Viola macloskeyi	42.1	4.8	0.5
Mean depth (cm)	4.50		3.2
Mean bare rock (percent)	11.58		14.5

Table 15. Composition of the *Diervilla sessilifolia* Type (N=7).

Species	Frequency	Mean Cover (Percent)	S.D.
Aster acuminatus	28.6	4.0	0
Carex debilis	28.6	4.5	0.7
Carex misera	28.6	15.0	7.1
Chelone lyonii	57.1	8.5	5.5
Cinna latifolia	14.3	5.0	
Diervilla sessilifolia	100.0	64.3	15.1
Eupatorium rugosum	57.1	15.0	5.0
Glyceria nubigena	14.3	4.0	
Houstonia serpyllifolia	42.9	11.3	14.9
Oxalis montana	14.3	4.0	
Rubus canadensis	28.6	7.0	4.2
Solidago glomerata	71.5	8.8	5.1
Viola macloskeyi	57.1	4.0	0
Mean depth (cm)	8.36		2.5
Mean bare rock (percent)	1.67		4.1

high elevations. The mean depth to obstruction was 8.4 cm and the mean bare rock percentage was 1.7, the highest and lowest values, respectively, of these variables among all community types. Diervilla sessilifolia was mentioned by Ramseur (1960) as one of the species of woody seedlings found in several of the different fire cherry community types which formed soon after fire disturbance at high elevations in the Southern Appalachians.

Rubus canadensis Type (N=25)

Rubus canadensis was the dominant plant in this community type (Table 16) and often formed dense stands in disturbed areas. A high elevation shrub common in open areas, Rubus canadensis had a mean cover of 39 percent. The mean depth to obstruction in this type was 4.9 cm and the mean bare rock percentage was 22. This community type occurred in slide margins (68 percent of the plots in this community type were located in margins) and in vegetation islands within slides. Solidago glomerata, Saxifraga michauxii, Aster acuminatus, Carex debilis and Carex misera were important associate species. Ramseur (1960) noted that Rubus canadensis occurred in abundant but localized stands at high elevations in the Southern Appalachians in the early stages of secondary succession after fire. Crandall (1958) found that Rubus canadensis was present with high frequency in open areas created by windthrow in

Table 16. Composition of the *Rubus canadensis* Type (N=25).

Species	Frequency	Mean Cover (Percent)	S.D.
Abies fraseri	12.0	4.3	0.6
Asplenium montanum	8.0	5.0	0
Aster acuminatus	36.0	9.4	9.0
Athyrium asplenioides	16.0	11.3	6.3
Calamagrostis cainii	8.0	4.5	0.7
Carex crinita	8.0	12.5	10.6
Carex debilis	48.0	6.7	3.9
Carex misera	40.0	6.7	2.9
Diervilla sessilifolia	8.0	4.5	0.7
Eupatorium rugosum	4.0	5.0	
Gentiana linearis	4.0	4.0	
Houstonia serpyllifolia	16.0	5.5	3.0
Hypericum graveolens	16.0	7.0	5.3
Krigia montana	4.0	4.0	
Oxalis montana	16.0	12.3	12.1
Picea rubens	8.0	15.0	14.1
Rhododendron minus	8.0	4.5	0.7
Rubus canadensis	100.0	39.2	19.9
Sambucus pubens	4.0	10.0	
Saxifraga michauxii	32.0	5.0	2.1
Solidago glomerata	48.0	14.5	10.1
Vaccinium erythrocarpum	12.0	4.3	0.6
Viola macloskeyi	40.0	4.6	0.5
Mean depth (cm)	4.87		4.6
Mean bare rock (percent)	22.00		30.7

Fraser fir forests above 6200 feet (1891 m) in the Great Smoky Mountains National Park.

Calamagrostis cainii Type (N=31)

Calamagrostis cainii, a grass endemic to Mt. Le Conte, dominated this community type (Table 17) which occurred on moist slopes within slides older than about ten years. Once established, *Calamagrostis cainii* formed dense mats. Its mean cover per plot in this community type was 36 percent. Ninety-seven percent of all plots in this community type occurred in slide centers. The mean depth to obstruction in this community type was 5.6 cm and the mean bare rock percentage was 4.7. *Calamagrostis cainii* appeared to grow only in open areas where soil had developed or accumulated as the mean depth to obstruction for this species in all slides was 6.2 cm. Large populations of *Calamagrostis cainii* were found only in older slides. *Gentiana linearis*, a heliophyte, was a very frequent associate species in this community type. *Viola macloskeyi* also appeared with high frequency.

Table 17. Composition of the *Calamagrostis cainii* Type (N=31).

Species	Frequency	Mean Cover (Percent)	S.D.
Abies fraseri	6.4	5.0	0
Angelica triquinata	9.7	4.7	0.5
Aster acuminatus	16.1	4.0	0
Calamagrostis cainii	100.0	36.0	14.5
Carex crinita	6.5	7.0	4.2
Carex debilis	6.5	5.0	0
Carex misera	38.7	10.8	6.1
Chelone lyonii	9.7	6.3	3.2
Gentiana linearis	61.3	9.0	4.8
Houstonia serpyllifolia	12.9	5.5	3.0
Hypericum graveolens	16.1	8.6	9.2
Krigia montana	9.7	4.7	0.6
Parnassia asarifolia	3.2	4.0	
Picea rubens	3.2	20.0	
Pyrus americana	3.2	4.0	
Rubus canadensis	6.5	4.0	0
Saxifraga michauxii	16.1	4.0	0
Solidago glomerata	12.9	7.5	5.0
Vaccinium erythrocarpum	3.2	4.0	
Viola macloskeyi	51.6	4.1	0.3
Mean depth (cm)	5.64		4.6
Mean bare rock (percent)	4.68		8.3

CHAPTER IX

DISCUSSION AND CONCLUSIONS

Debris slides are a type of infrequent but severe disturbance which greatly affects the plant communities in and immediately around the area of slide formation. Many characteristics of debris slides are common to other disturbed areas as well. The debris slides in this study play a most significant role as a type of habitat vital to several disturbance-dependent species in the flora of the Great Smoky Mountains National Park.

Disturbance is a factor present to some degree in all plant communities. Grime (1977) describes disturbance as any activity which results in partial or total destruction of the plant biomass. A more traditional definition views disturbance as the sum of catastrophic events which change an environment physically and result in structural changes within the communities therein. Yet disturbance includes a continuum of levels of severity and thus can be viewed as a factor at work at some level in most plant communities (White 1979). Disturbances vary in frequency and predictability and they interact intimately with other well-studied environmental gradients such as temperature, moisture, solar radiation, topography, and substrate (Bratton et al. 1979). Disturbance and stress are the two external factors described by Grime (1977) as factors limiting plant biomass.

Recurrent disturbance within an ecosystem acts to maintain species diversity by exerting selective pressure in the evolution of species strategies able to cope with the disturbed environment (White 1979). By creating open environmental patches within forested slopes at high elevation, debris slides provide an additional habitat type available for colonization. As revegetation occurs after a debris slide forms, species diversity increases as species new to the site appear. White et al. (1984) note that peak plant diversity on the grassy balds in the Great Smoky Mountains was not at the time of most intense disturbance when the area was grazed by sheep for seventy years following human habitation, but during the twenty year period of post-disturbance recovery.

Debris slides are an example of disturbance at an extreme degree. Although their effects are highly localized within the immediate area, their importance in terms of rare plant habitat is greater than their areal extent alone might at first indicate. In a paper assessing the effects of a variety of natural disturbances upon vegetation, Bratton et al. (1979) note that debris slides within the Great Smoky Mountains National Park are natural and beneficial in the maintenance of landscape heterogeneity.

The extreme severity of disturbance is of great importance in determining the subsequent composition of the post-disturbance vegetation in the debris slide. Differences among the slides in environmental parameters such as aspect and moisture, factors which normally would play a large role in producing site-to-site differences in vegetation composition among more stable, less stressed areas, become much less important in areas in which disturbance and stress are so severe that the number of possible colonizers is limited. In a study of debris slide revegetation in the White Mountains of New Hampshire, Flaccus (1958) noted that the revegetation process on the most disturbed slide portions (bare cliffs and ledges, talus deposits, and eroded areas) within all slides studied was unexpectedly uniform in spite of differences in aspect, moisture, and solar radiation among different slides. Because relatively few pioneer species were involved and these species can colonize a variety of habitats, Flaccus concluded that successions among all debris slides studied were similar in spite of variation in ecological factors. The slides in this study showed the same revegetation patterns with very few differences from slide to slide as did these slides in the White Mountains.

The environmental stresses found within debris slides of this study appear similar to those described in other studies of landslide or earth movement revegetation. Langenheim (1956) described revegetation of a subalpine earthflow in Colorado, the surface of which was composed of unstable shale fragments. High temperatures, substrate instability, low moisture near the substrate surface, and low nitrogen content were some of the extreme conditions found in most portions of the earthflow. The slides studied by Flaccus (1958) in the White Mountains of New Hampshire shared the following environmental and topographic conditions: intense solar radiation, high transpiration stress, temperature extremes, lack of one or more mineral nutrients in available form, insufficient nitrogen, instability of rooting medium, and susceptibility to water erosion. In a study of plant succession in timberline areas in south-central Chile, Veblen et al. (1977) described steep slopes covered with loose, black, coarse-textured material of volcanic origin. The porosity of this substrate coupled with its dark color contributed to high ground temperatures during the summer months, resulting in extremely arid conditions. High winds and erosion by water were additional environmental stresses. The debris slides on Mt. Le Conte also had large areas of exposed bedrock that was very dark in color, and the little soil that had accumulated in these areas appeared very dry on most visits to these slide sections. Erosion by water during rainstorms periodically disturbed the slides in this study.

Only those species capable of withstanding these conditions can survive and reproduce in most portions of the debris slide scar. While revegetation in the Mt. Le Conte slides may proceed quite rapidly in debris slide margins where soil slump has occurred or in transportation-gully zones where considerable soil is available along lateral edges of the central gully, it is much slower in the head zone and in the erosion-transportation zone where exposed bedrock and large boulders predominate. Hardy heliophytic forbs and graminoids capable of withstanding periodic drought and intense solar radiation appeared in greatest numbers and cover on most slides. With considerable elevation, slope steepness, and bare rock cover and subsequent decreases in soil depth, the herbs, graminoids, mosses, and lichens were the major constituents of the flora.

Trees seemed to appear much later, if at all, in areas of very shallow or moving soil, a phenomenon which was similar to that observed in other landslides and earth movements. Tree seedlings were often stunted. Flaccus (1958) noted in debris slides of the

White Mountains that although trees appeared as a part of the revegetation process throughout all parts of the slide, they appeared severely stressed in broad eroded areas, talus deposits, and ledges. The birches in his study areas showed stunting and yellowing of leaf margins and the conifers were chlorotic and also stunted. Subsequent analyses there showed very low levels of soil calcium, magnesium, potassium, and available phosphorus. Nitrogen was presumed to be low because organic matter appeared scarce. In most debris slides, trees usually grew first at the lateral edges, and later appeared in the centers if sufficient soil development had occurred. This pattern was observed by the author in the slides on Mt. Le Conte and by Scott (1972) in debris slides in the Blue Ridge Mountains, where the youngest trees were found in the centers of older debris slides.

Sometimes one or several herbs or graminoids will be very evident and highly successful colonizers in debris slides, appearing with large percent cover throughout almost all parts of a slide. This pattern is especially evident in rocky slide centers, exposed heads, or other slow-to-revegetate areas. Saxifraga michauxii , a perennial herb present in high frequencies throughout all slides of this study, was one such example. It grew in 55 percent of all plots sampled, a frequency higher than that of any other vascular plant in this study. Langenheim (1956) found that *Chaenactis alpina*, a composite, occurred with high frequency and cover throughout a subalpine earthflow in Colorado, often in relatively pure stands where loose shale fragments formed an unstable substrate, similar to the way in which *Saxifraga michauxii* grew in slides on Mt. Le Conte. In the least stable portion of the earthflow, *Chaenactis alpina* was one of the few species able to maintain itself. Although no attempts were made to measure the physiological capacity of *Chaenactis alpina* individuals within the earthflow, Langenheim concluded that this species thrives under extreme conditions of instability, insolation and substrate surface conditions of high temperatures and low moisture.

Veblen et al. (1977) found a sparse cover of herbs and graminoids ranging from 5 to 20 percent in the rocky rubble substrate of high elevation fellfield slopes in the Andes of south-central Chile. Plant density decreased with increasing altitude. Plant cover greatly increased on level and protected sites within the fell-fields as shrubs and other components of the adjacent scrub-grassland vegetation type were then able to become established.

In view of the considerable array of stresses facing these plants, it is apparent that those species most capable of surviving in the most stressful portions of these debris slides are not those which are good competitors but rather those which are the most stress-tolerant. Grime (1977) examines possible combinations of levels of stress and disturbance and describes three primary plant strategies. Environments of low stress and low disturbance bring about the evolution of competitive plants, while high stress with low disturbance favors stress-tolerant plants and low stress with high disturbance favors ruderal plants (i.e., flowering plants adapted to persistent and severe disturbance). The three strategies of Grime´s triangle model represent extremes and a range of equilibria exist among them. Plants colonizing inhospitable debris slides areas could be classified as stress-tolerant ruderals, one of the four secondary strategies described by Grime. These are plants which are adapted to lightly disturbed unproductive habitats such as dry rock outcrops and cliff crevices. In unproductive areas where soil fertility is low (such as broad eroded areas of exposed bedrock or shallow unstable rubble within these debris slides) the possible effects of competition on any species present are far less important than those of the stringent environment itself. Good competitors thus tend to live in undisturbed areas (White 1979).

Similar spatial patterns of revegetation can be seen in these debris slides and in other related areas described in the literature. On highly disturbed sites, initial colonizers often become established in a crevice, near the base of a boulder, or near a small ledge. These plants will help to anchor loose substrate and may also retain soil material as it falls down from upper parts of the slide or forms in place. Eventually, areas slightly more stable than the surrounding terrain are created. The formation of vegetation "islands", small discrete groupings of plants that get started in this way, was observed in this study. Revegetation patterns like these were noted in other studies of revegetation of landslides and other areas. On a talus slope in Idaho, Daubenmire and Slipp (1943) noted island-like thickets developing in the lee of large boulders too deeply imbedded in the detritus to be affected by surface movement. These thickets formed at right angles to the contour lines as small rocks and other debris tended to be diverted to either side of the boulder. Large amounts of water rushing down the debris slides of this study during and after a rainstorm also will move around such vegetation islands, removing loose material and forming shallow water channels on the upper parts of the slide and, finally, a central gully in the transportation-gully zone. Veblen et al. (1977) noticed similar patterns in high elevation slopes in the Andes where vegetation appeared with the greatest frequency on linear ridges oriented downslope. The spatial arrangement of vegetation is first initiated by the establishment of a small colony of plants which then decreases the chance of downslope movement of substrate and protects the site directly downslope from water erosion. With time, a topographic differentiation into ridges and furrows occurs, with very little plant cover in the furrows due to alternating water erosion and damage to plants from movement of coarse materials. On less disturbed, more stable portions of debris slides, trees became established, especially in the lateral margins.

The patchiness of the debris slide habitat is very important in determining the long-term vegetation composition. In those portions of the slide where substantial soil has formed or slumped from the margin, revegetation may quickly become fairly extensive, producing *Solidago*-*Diervilla*-*Rubus* communities similar to those occurring in clearings formed by windthrow, and, eventually, spruce and fir canopy. Areas too steep to support significant soil formation or consisting almost exclusively of large expanses of bedrock will probably show little revegetation beyond forb and shrub development and an occasional small tree. The degree of available soil moisture in any section of the slide may be the most significant factor in determining vegetation composition. Daubenmire and Slipp (1943) found available soil moisture to be the primary factor in explaining the very different floras of north- and south-facing talus slopes in northern Idaho. In the debris slides of this study, areas with little soil and thus low water-holding capacity tended to support a number of hardy forbs and graminoids, Saxifraga michauxii, Carex misera, and Carex debilis being some of the high frequency species. Seepage areas, such as the grassy head of TB-3, the oldest slide, are often vegetated by Calamagrostis cainii, Parnassia asarifolia, and Gentiana linearis, species which require high moisture levels and are found in bogs, seepage areas, and wet meadows (Radford et al. 1968). Species characteristic of xeric, alluvial, or hydric successions tend to be those which are present early in the successional timetable, while species of mesic environments appear in a climax vegetation type (White 1979). Sufficient soil development must occur in order to enable the establishment of mesic species.

The seven community types identified in this study by cluster analysis represent different points along the continuum of post-slide recovery. The Saxifraga michauxii type and the mixed herb type were both found in young debris slides where soil was very shallow and the cover of bare rock was high. Species number may be initially high in a very young slide; several of these small herbs and graminoids will remain and continue to thrive in these disturbed areas. The *Carex misera* type appeared in unstable areas within somewhat older debris slides. The *Solidago glomerata* type, the *Diervilla sessilifolia* type, and the *Rubus canadensis* type were found in slide margins (especially in transportation-gully zones) or in older debris slides where soil depth and bare rock cover were high and low, respectively. These three community types constituted the primary flora of somewhat older, recovering debris slides. A final community type, the *Calamagrostis cainii* type, occurred in older, moist debris slide centers.

Recovery rates among debris slides depend upon the severity of the initial disturbance (how much of the slide was scoured to bedrock), the size of the slide (important in terms of distance to soil slump and adjacent seed sources), slope angle, elevation, and the degree of stress imposed by other environmental and physiographic features. The time span included in this study is comparatively brief when compared to studies of primary succession on bare rock which indicate a minimum of 200 years for succession to mesic temperate forests to occur (Barbour et al. 1980). Scott (1972) noted that the debris slides on Mt. Le Conte studied by Bogucki (1970) had a much slower rate of recovery than slides which he studied in the Blue Ridge

Mountains. This was due, he concluded, to the exceptionally high elevation, unusually steep slopes, and large degree of exposure in the Mt. Le Conte area and because most of these slides bared considerably more bedrock than did those in the Blue Ridge Mountains.

Several of the species found in debris slides on Mt. Le Conte are rare species which occur in these and similar open areas at high elevations. Many high elevation areas in the Southern Appalachians like these debris slides acted as refugia for boreal species which became fragmented in their distribution when they were restricted to the highest elevations during a time of postglacial warming some 5,000 years ago when the lower boundary of spruce-fir forest moved upward to 5,700 feet (Whittaker 1956). Thus, many species that are found only on similar high peaks (many of which are separated by distances too great for quick species immigration) are today present at high elevations in the Appalachians. White et al. (1984) point out that these areas might be viewed as a series of high elevation islands of northern community types and that such open habitats as debris slide scars, cliffs, and seepage meadows are themselves a series of patchily distributed islands within the high peak forest matrix. These habitats support species that may be remnants from a southern alpine flora, many species of which became extinct during post-glacial warming.

Within the Great Smoky Mountains National Park, Sevier County, Tennessee, which includes Mt. Le Conte, is a particularly important center of distribution of rare species (White and Wofford 1984). Several of these rare species occurred on debris slides on Mt. Le Conte. Most of these species are found only in habitat types that are limited in size and frequency, such as crevices of usually moist cliff faces, high elevation seepage areas, disturbed areas, rocky wet ledges at high elevations, and balds. The limited availability of habitat means that a species population may consist of a small number of individuals and may be separated by large distances from the next nearest population. Indeed, the isolation of these habitat patches and the small population sizes present in them may even have resulted in genetic divergence in some species (White et al. 1984).

Several of the species found on debris slides, such as Carex misera, require early seral stages and are therefore threatened by succession (Somers 1982). These species may be thought of as disturbance-dependent because they need open habitats like those listed above, locations which, at high elevations, are usually without canopy cover and without competition from other species present in high frequency and cover.

Five rare species within the state of Tennessee are entirely restricted to the upper slopes of Mt. Le Conte (White and Wofford 1984). Three of these species, *Calamagrostis cainii*, *Gentiana linearis*, and *Krigia montana*, were found on debris slides included in this study. *Calamagrostis cainii* is endemic to the upper slopes of Mt. Le Conte. These three species are listed as threatened within Tennessee (Somers 1982). Two other species found on the debris slides, *Glyceria nubigena* and *Cacalia rugelia*, are unknown in Tennessee outside of the park. *Glyceria nubigena*, a narrow endemic to the Great Smoky Mountains (White et al. 1984), has scattered populations within the park and was found in three debris slides. It is listed as endangered nationally (Ayensu and DeFilipps 1978) and in Tennessee (Somers 1982). *Cacalia rugelia* is listed as threatened nationally (Ayensu and DeFilipps 1978) and in Tennessee (Somers 1982).

Five additional species which also occurred in debris slides of the study area are of special concern or threatened status and are known from five or fewer counties in Tennessee. These are *Scirpus cespitosus*, *Carex misera*, *Menziesia pilosa*, *Hypericum graveolens*, and *Abies fraseri*. *Scirpus cespitosus* is listed as threatened within

Tennessee (Somers 1982). Carex misera, listed as threatened nationally (Ayensu and DeFilipps 1978) and within Tennessee (Somers 1982), was found very frequently throughout all of the debris slides, occurring in 26 percent of all plots. Menziesia pilosa is listed as of special concern within Tennessee (Somers 1982). Hypericum graveolens is listed as threatened within Tennessee (Somers 1982). Abies fraseri was found at low frequencies in all of the slides but one. It is listed as being of special concern in Tennessee (Somers 1982) and populations within the park are suffering severe damage due to infestations of the balsam woolly aphid, an exotic insect which threatens to eliminate mature Abies fraseri at its upper elevational range within the park (Bratton et al. 1979).

Population data in areas undergoing community change, such as the nine debris slides in this study, is essential because it provides a population description against which population changes from year to year can be measured (Bratton et al. 1979). Although management decisions that might be made concerning the control of other natural disturbance such as fire cannot be made with debris slides, data concerning the species that are present are essential to aid in monitoring what may be sensitive populations of rare species. For difficult-to-manage disturbances such as these, species-oriented management rather than system-oriented management can be selected (Bratton et al. 1979). Baseline data such as these can be used to evaluate the effects, if any, of management decisions on specific populations. A knowledge of the size and stability of the populations of rare species is basic to any active policy of conservation (Bradshaw and Doody 1978). Additional information, of course, is still necessary to make informed decisions concerning a rare species. An in-depth understanding of the biology of the species, including life strategy and details of the life cycle, is ultimately necessary to be able to make predictive statements of coexistence or replacement in successional areas such as these (Werner 1976).

Debris slides are dynamic areas which are subject to unpredictable, continuous natural disturbance as ongoing weathering, erosion, and occasional slide enlargement occur. A lack of disturbance, allowing succession to proceed uninterrupted, can also threaten disturbance-dependent species. Human-caused disturbance may also be a factor in some debris slides. One of the slides in this study, SB-8, is crossed twice by the Alum Cave Bluffs trail, and hikers were witnessed by the author occasionally leaving the trail to walk through portions of the slide. Another slide, SB-9, lies adjacent to SB-8, bordering a bend in the Alum Cave Bluffs trail, and it may also be subjected to disturbance from off-trail hikers. Documenting the sequence of events during colonization can make it possible to attempt to predict changes in vegetation patterns through time as revegetation continues uninterrupted or major disturbance intervenes.

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