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# PIEDMONT-COVE DEPOSITS OF DELLWOOD QUADRANGLE, GREAT SMOKY MOUNTAINS, NORTH CAROLINA, U.S.A.: SOME ASPECTS OF SEDIMENTOLOGY AND WEATHERING

Abstract

Deposits analogous to alluvial fans occur in many piedmont coves of the southern Appalachian Mountains. In the Dellwood quadrangle of North Carolina these "fans" consist largely of bouldery diamictons lacking sorting or stratification. Because the fans presently seem to be undergoing erosion rather than deposition, many observers have attributed them to an ice-age periglacial regime, perhaps involving gelifluction. Other observers have suggested that they originate as a consequence of debris flows during rare, catastrophic rainstorms, and that climate is not involved. A study of the texture, pebble-roundness, clast-fabric, and sedimentary structures of the fan sediments, however, reveals little evidence of relict gelifluction, although this process cannot be eliminated as a possibility.

Origin by debris flow thus seems more likely, but this does not necessarily imply that the fans are unrelated to Quaternary climatic change. At least two ages of fan deposits occur in the study area, and a discriminant analysis based on three weathering indices (percent clay, reddest hue, and percent weathered clasts) measured at 28 sites shows that the younger deposits form a discrete group separated from the older deposits by a hiatus in weathering intensity, and thus presumably also by a hiatus in time. This finding indicates episodic deposition, and, combined with the fact that the weathering characteristics of the younger deposits are compatible with a late Wisconsin/early Holocene age, suggests that the last episode of deposition may have taken place after climatic amelioration at the end of the Wisconsin, when increased precipitation and an abundance of frost-produced debris at higher elevations probably temporarily increased the size and frequency of debris flows.

## INTRODUCTION

Deposits of bouldery colluvium and alluvium are widespread along the piedmont slopes of higher mountains in the Blue Ridge physiographic province of the southeastern United States. The largest deposits are found in coves, the name locally used for relatively gently sloping embayments in the mountain front. Coves usually occur near the mouths of first- or second-order stream valleys, and sometimes the deposits in them are fan-shaped. A number of geologists and geomorphologists have commented on these deposits, usually attributing them to the effects of Pleistocene glacial climates. Although one dissertation has been devoted largely to these features, there has been little investigation of their sedimentology. The present paper reports the results of an investigation of the sedimentology of piedmont-cove deposits on the U.S. Geological Survey $7\frac{1'}{2} \times 7\frac{1'}{2}$ Dellwood quadrangle, North Carolina.

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## GEOLOGIC SETTING

The Dellwood quadrangle is located near the southeastern margin of the Great Smoky Mountains in North Carolina (Fig. 1). The relief on the quadrangle is 920 m, 1652 m being the elevation of the highest peak. The bedrock is comprised of a thick sequence of metamorphosed sedimentary rocks of late Precambrian age, known as the Ocoee series, that rest on a "basement" complex of granite and meta-sedimentary gneisses. The Ocoee series is subdivided into the older Snowbird group and the younger Great Smoky group. The former includes four intertonguing formations which consist of variously metamorphosed sandstone, siltstone, shale, and mudstone derived in large part from the basement rocks. The Great Smoky group consists of variably metamorphosed clastic sedimentary rocks considerably coarser and more varied in texture and composition than the Snowbird group.

The degree of metamorphism in the Dellwood quadrangle is high. The metamorphic map of HADLEY and GOLDSMITH (1963, Pl.3) shows the quadrangle to be in the staurolite and kyanite zones. Structurally, the Dellwood quadrangle is dominated by anticlinal uplifts of basement rocks and intervening synclines of the Ocoee series.

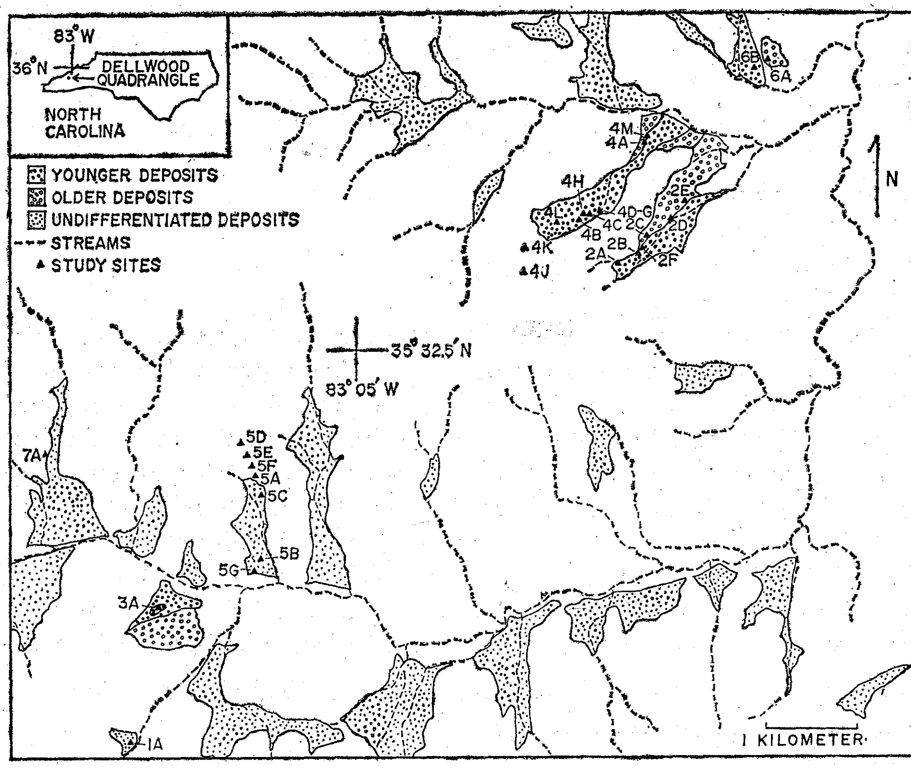



Fig. 1. Map of study area showing piedmont-cove deposits and location of study sites. Map is after Hadley and Goldsmith (1963), with some slight modifications

HADLEY and GOLDSMITH (1963, Pl.2) devoted more attention to the surficial geology than have most geologists in this region, and it was for this reason that I selected the Dellwood quadrangle as a study area. Not only did HADLEY and GOLDSMITH distinguish cove "fans" from other alluvial and colluvial deposits on their map, but on four of the fans they distinguished between older and younger deposits.

## PREVIOUS WORK

Piedmont-cove "fans" have been described by a number of geologists primarily engaged in bedrock mapping in the southern Blue Ridge province. (Because of its popular usage, I will employ the term "fans" to designate the piedmont-cove deposits. However, it should be pointed out that the majority of such features have a form that lacks even a vague resemblance to the form of classical alluvial fans, which approximates a segment of a cone. Therefore, piedmont-cove fans usually are analogous to classical alluvial fans only in that both occur on mountain piedmonts). In the Great Smoky Mountains, fans have been described by HAMILTON (1961), HADLEY and GOLDSMITH (1963), and KING (1964). The largest fans occur not in the study area, but in the northern part of these mountains. HADLEY and GOLDSMITH (1963), for example, noted that in the northeastern Great Smoky Mountains, fans occupy more than 24 $km^2$, and the two largest fans cover more than 3.2 $km^2$ each.

All of the above authors have noted that the fans are related to no particular bedrock formation, but rather the feature shared by all is that they occur in valleys immediately adjacent to high mountains that consist of thick-bedded sandstones of the Great Smoky group. The sediments in these fans range from an unsorted, unstratified diamicton to bouldery alluvium, with the proportion of the latter usually increasing in a downfan direction. Minimum thicknesses of over 20 m have been reported at some locations.

By far the most detailed study of piedmont-cove fans was by MICHALEK (1968), who studied these features over the entire southern Blue Ridge province. He reported mean slopes of 5° to 12° for medium and large fans, with basal slopes as low as 1° to 2°, but more commonly 4° to 6°. Headward slopes approach 20°. Small fans have mean slopes of 5° to 20°, with an average of 10° to 12°. He noted that the middle and upper parts of practically all fans are littered with blocks, and that there is some tendency for the blocks to decrease in size in a downfan direction. He also observed that the upper parts of the fans pass into the coarse, blocky colluvium of the mountain slopes with no conspicuous topographic break.

The morphometry of the Dellwood fans has been examined in another paper (MILLS, 1982). To summarize the form of these features, however, of the 34 fans on the quadrangle, the mean area is 0.29 $km^2$, the mean slope is 10°, the mean elevation of the tops of the fans is 1109 m, the mean fan relief is 173 m, the mean fan length is 1004 m, and the mean fan width is 491 m.

The paleoclimatic significance of piedmont-cove deposits has been a subject of debate. Most authors have interpreted these fans as relict glacial-age features, perhaps the product of gelifluction (e.g. HAMILTON, 1961; HADLEY and GOLDSMITH, 1963; KING, 1964; MICHALEK, 1968). As evidence, MICHALEK (1968) cited the following points: 1) the fans presently appear to be undergoing erosion rather than deposition; 2) block fields cover the upper parts of the fans; 3) no fans are found below 700 m; and 4) fans diminish in both number and development southward, becoming uncommon south of Asheville, North Carolina (latitude about 35°34′ N).

Other authors, however, including HACK and GOODLETT (1960) and GRYTA and BARTHOLOMEW (1977), have contended that fans in the southern Appalachians may be formed by debris flows set off by rare, catastrophic rainstorms. This hypothesis became much more plausible after the night of August 19—20, 1969, when Hurricane Camille dropped up to 710 mm of rain in a period of less than 8 hours on some areas in the Blue Ridge Mountains of central Virginia. Although the relief in this area is less than 400 m, hundreds of debris flows were set off by this deluge, some of which covered the surfaces of small fans with bouldery debris to mean depths of up to 60 cm (WILLIAMS and GUY, 1973). These deposits were very similar to the piedmont-cove deposits in the study area. Even though such a rainfall probably has a recurrence interval on the order of 1000 years (THOMPSON, 1969), a sequence of such storms conceivably could build up sizeable fans within several tens of thousands of years. Such an origin could account for the first two above-mentioned points listed by MICHALEK (1968) as evidence of fan periglacial origin, but could not account for the altitudinal and latitudinal distributions of the fans. However, until topographic and lithologic differences associated with altitude have been rigorously eliminated as possible causes, such distributions seem to constitute, by themselves, inadequate evidence for a periglacial origin.

More definite proof of periglacial origin must be one of two types. The best proof, of course, would be radiocarbon dates showing piedmont-cove deposits to date from the last glaciation. Unfortunately, no organics have yet been recovered from these deposits. The other possible proof would be to demonstrate sedimentological features that are strongly associated with periglacial environments. Gelifluction presumably would be the major periglacial process involved in the formation of fans. BENEDICT (1976) listed nine characteristics of relict gelifluction deposits:

1) Topographic expression in the form of gelifluction sheets, benches, lobes, and streams.

2) Occurrence on the moister parts of the hillslope.

3) Lithology and angularity of fragments indicating a source immediately upslope.

4) A high percentage of silt and coarse clay (which favours gelifluction but is by no means a prerequisite).

5) Some sorting. Despite the homogenizing effect of gelifluction, some

sorting due to other processes, especially frost action, is likely. There may be crude stratification (e. g. DENNY, 1956, p. 31; WASHBURN, 1980; p. 217), or surface patterinng that trends in a downslope direction (BENEDICT, 1970, p. 203)

6) A platy and sometimes vesicular soil structure.

7) A mottled or gleyed color because of seasonal waterlogging and the presence of buried organic matter.

8) A clast fabric in which the preferred long-axis orientation is parallel to the direction of slope and imbricated upslope. Secondary oblique orientations at angles of 30° to 50° with the direction of movement are also common, as is a minor transverse orientation. Where movement is obstructed, the transverse orientation becomes well developed. Tabular particles of all sizes tend to lie with their A—B planes parallel to the surface or imbricated upslope.

9) Buried organic matter, representing soil humus overrun by the deposit during its downslope advance.

Unfortunately, many of the above properties are either not very distinctive or are unlikely to survive for long after gelifluction ceases. Hence, gelifluction may be difficult to recognize from its deposits.

Some authors have suggested that although the fabric patterns described above are likely to occur in many mass-movement deposits, the strength of gelifluction fabrics may be distinctive, if not unique. KIRBY (1967), for example, reported fabric strength from relict gelifluction deposits to be on the order of twice the strengths of typical till fabrics (where chi-square values were used as strength measures). BROCHU (1978), studying deposits in the North American Arctic, made similar observations. Using as a measure of strength the number of clasts whose long-axis azimuth was within 45° of the slope direction, BROCHU found that, on average, 79.5% of clasts in gelifluction deposits were so oriented but only 36% of those in gravity-slope deposits and 33% of those in fluvial or glaciofluvial deposits.

In contrast to the strong fabrics reported for gelifluction deposits, debris-flow deposits may have weak fabrics. WILLIAMS and GUY (1973), although they made no fabric measurements on the deposits laid down by the floods accompanying Hurricane Camille, did observe that except for the fact that many rocks seemed to be lying on their long and intermediate axes, the deposits looked as if they had been "shaken in a giant mixer and dumped". Although LINDSAY (1968) demonstrated that on a theoretical basis strong alignment of clast long axes should develop in debris flows, and presented four fabrics measured in presumed mudflows of Permian age, I have seen no reports of fabrics measured in bouldery debris flows with a texture similar to the fan deposits in Dellwood quadrangle. I have made several fabric measurements on volcanic debris flows in the Cascade Range of Washington, which had textures roughly similar to those of the fan deposits, and found very weak fabrics. Hence, as the debris flow is probably the main alternative to gelifluction in accounting for the transport of fan debris, fabric strength may allow the two to be distingushed, although more measurements on modern debris flows are needed in order to establish whether a weak fabric is indeed a consistent feature of these deposits.

Although gelifluction would probably be the predominant periglacial process on the fans, the presence of other periglacial features on the fans would provide support for the periglacial hypothesis. A list of such features is provided by WASHBURN (1980, p. 282—283), for example. Some of these, such as involutions and patterned ground, are somewhat more distinctive than are gelifluction deposits.

Most descriptions of piedmont-cove deposits have noted that multiple ages of such deposits occur. The age differences are indicated by differences in degree of weathering and soil development and by topographic relationships. In the Dellwood quadrangle, HADLEY and GOLDSMITH (1963) reported two well-defined levels of deposits, with the younger deposits at a slightly lower level and incised into the older deposits (see Fig. 1). The higher deposits are characterized by "abundant reddish-brown clayey matrix and many rotten boulders of gneiss, in which only the more resistant schist and quartzose rocks are not decomposed", and the lower deposits by "less-weathered fragments in a gray or brown matrix". They interpreted these two deposits as representing two episodes of colluviation/ /alluviation separated by a significant erosion interval, and suggested that the two episodes may have occurred during the early and late Wisconsin.

HAMILTON (1961), however, also noted several levels of fan surfaces in the Richardson Cove and Jones Cove Quadrangle of the northern Great Smoky Mountains, but concluded that "such surfaces merge complexly, and no simple age classification of the surfaces seems possible". HACK (1965) came to similar conclusions concerning what he termed "piedmont alluvial aprons" in the Shenandoah Valley of Virginia. He observed that the aprons are arranged into terraces, the higher of which are more weathered and eroded than the lower. However, he thought that there was no particular grouping of the terraces with respect to age, a conclusion compatible with his belief that these features were the product of a continuous rather than an episodic process.

This difference in opinion as to whether the fans can be placed into definite age groups, or whether there is a continuum from the youngest to the oldest with no particular grouping, represents an important question. If HADLEY and GOLDSMITH (1963) are correct that fan deposits do fall into distinct age categories, the chances that such deposits are related to Quaternary climatic cycles seem much higher than if HAMILTON (1961) and HACK (1965) are correct. In the absence of radiocarbon-datable organic material, one way in which this question may be addressed is by relative-dating techniques. Such techniques involve the measurement of age-dependent weathering criteria and have commonly been used as aid to the correlation of glacial deposits in the absence of absolute dates. A number of relative-dating criteria have been listed, for example, by BURKE and BIRKELAND (1979) and MILLER (1979). This approach might be used to decide whether or not fan deposits do tend to fall into distinct groups, thereby helping to decide whether or not they are related to climatic change.

## PROCEDURE

About half of the fans mapped by HADLEY and GOLDSMITH (1963) were visited. For the most part I concurred with their mapping, the main uncertainty of which is where to place the boundary between the fans and the thinner colluvium on the adjacent sideslope of the cove. Detailed sedimentological studies were made on seven fans, including the four that were subdivided into "younger" and "older" by HADLEY and GOLDSMITH. A number of cuts in fan deposits, as well as in "normal" thin colluvium occurring on steep side- or headslopes, were examined, with special emphasis placed on looking for sedimentary structures and contacts, either between superimposed depositional units or between fan deposits and bedrock.

A total of 62 fine samples were obtained from fan deposits and "normal" colluvium. The percent sand, silt, and clay in these deposits was determined in the laboratory by hydrometer analysis. Mean roundness was determined for 9 samples of 25 pebbles (16—32 mm in intermediate diameter) by means of KRUMBEIN'S (1941) visual comparison chart. The azimuthal direction and the dip of the long axes of 25 to 50 clasts were measured at 11 sites. The criteria for clast selection were: clast relatively unweathered, length between 2 and 15 cm, and a long axis: intermediate axis ratio of at least 1.5 : 1. All sites were located below the root zone.

The data for each fabric site were plotted on Schmidt equal-area nets and contoured by KAMB'S (1959) method. In addition, fabrics were subjected to both two- and three-dimensional statistical analysis. For the two-dimensional analysis (long-axis direction only), KRUMBEIN'S (1939) method was used. This method allows the resultant vector (r) and the vector magnitude (L%) to be calculated. The latter can be tested against a random sample by means of a diagram provided by CURRAY (1956). For three-dimensional analysis, the eigenvalue method was used (SCHEIDEGGER, 1965; MARK, 1973). This method produces three eigenvalues $\lambda_1 \geqslant \lambda_2 \geqslant \lambda_3$ and their associated mutually perpendicular eigenvectors $V_1$, $V_2$, and $V_3$. $V_1$ represents the axis of maximum concentration of the long axes and $V_3$ the axis of minimum concentration (which is, in effect, the pole to the preferred plane of the long axes). The quantities $S_1$, $S_2$, and $S_3$ are defined by $S_i = \lambda_i/N$. A table provided by ANDERSON and STEPHENS (1971) allows $S_1$ and $S_3$ values to be tested in order to determine whether $V_1$ and $V_3$ are significantly different from the values expected for a random sample of axes drawn from a uniform population.

A simple study of weathering characteristics was also made. It was desirable to describe the weathering at each exposure in a quantitative fashion in order to see if the deposits could be placed into discrete groups on the basis of weathering intensity, for reasons discussed earlier. To accomplish this, three weathering indices were determined at each exposure: first, the maximum (if more than one sample had been taken) percent clay in the less-than-2-mm fraction; second, the reddest hue as measured with a Munsell color chart; and third, the percent weathered clasts. The latter index was determined as follows. A total of 25 clasts approximately in the pebble size range were randomly selected from the exposure and classified into one of two weathering categories on the basis of whether or not they could be broken apart by hand (into pieces the size of granules or smaller).

The above three variables were determined at 28 sites. Based on Hadley and Goldsmith's (1963) observations, it was hypothesized that there were two distinct age groups of deposits, and each site was therefore classified as "young" or "old" on a semi-objective basis after the weathering indices were measured. Then, in order to decide wheather the two groups were really distinct, rather than merely representing the arbitrary division of a continuum, a discriminant analysis (Klecka, 1975) was performed and a plot made of the discriminant scores.

## RESULTS

### GENERAL OBSERVATIONS

Wells are almost non-existent in the coves, water supplies generally being obtained from springs. However, wells drilled through similar slope deposits elsewhere suggest that the mean thickness of the deposits is unlikely to be more than 15 to 20 m. The cuts and excavations examined ranged in vertical height from 1 to 4 m. Most commonly the cove deposits consist of a bouldery, matrix--supported diamicton, lacking any sorting or stratification, with angular clasts (e. g. Pl. 1). Such sediment is almost ubiquitous on small fans and on the upper parts of large fans. Although diamictions are common even on the lower parts of large fans, in such locations sediment showing a fluvial influence can also be observed. For example, site 4M (Fig. 1) reveals a clast-supported diamicton with a relatively small amount of matrix, in which pebbles are rounded to a degree. Interestingly, a higher proportion of the older, highly weathered deposits appear to be partly alluvial in nature than do the younger deposits. For example, sites 2E, 3A, and 4A (Fig. 1) all consisted of deposits poor in matrix and with rounded clasts; the size range was also somewhat more restricted than that in the diamictons, with clasts being mainly in the pebble and cobble range. Site 2E is shown in Pl. 2. It is unclear whether this finding indicates that normal alluvial processes were more prevalent when the older deposits were laid down than when the younger ones were, or perhaps simply that such stony deposits are preferentially preserved because of their greater resistance to erosion.

At only one site was evidence for alternation of fluvial and nonfluvial deposition seen. At site 1A (Fig. 1) a thin (2 cm-thick) layer of coarse sand and granules separated an overlying 85 cm-thick diamicton from another diamicton of undetermined thickness beneath. At several sites younger fan deposits were observed overlying older ones. For example, at site 2B (Fig. 1), 1 m or so of younger sideslope colluvium overlay old, highly weathered fan deposits. At site 4C (Fig. 1) a younger fan deposit about 1 m thick overlay an older, more weathered fan deposit. At both sites the contact between the two deposits was gradational.

At several exposures colluvium or fan deposits were observed to overlie saprolitized bedrock; in these cases the contacts were fairly sharp. The most spectacular example was seen at site 5G (Fig. 1, Pl. 3), where slightly weathered fan deposits occupy a channel incised into saprolitized gneiss. The fact that the deposits in the channel are relatively young indicates that the channel must have been incised into saprolite, rather than into bedrock which subsequently became saprolitized beneath an unconsolidated mantle. Another example of cove deposits overlying saprolite occurs at site 2A.

Although it is true that only a few contacts between saprolite and overlying fan deposits were seen, it is also true that such deposits were never seen overlying unweathered bedrock. It therefore is thought likely that the cove deposits for the most part rest upon saprolite rather than bedrock.

No sedimentary or geomorphic features known to be strongly associated with periglacial conditions were observed.

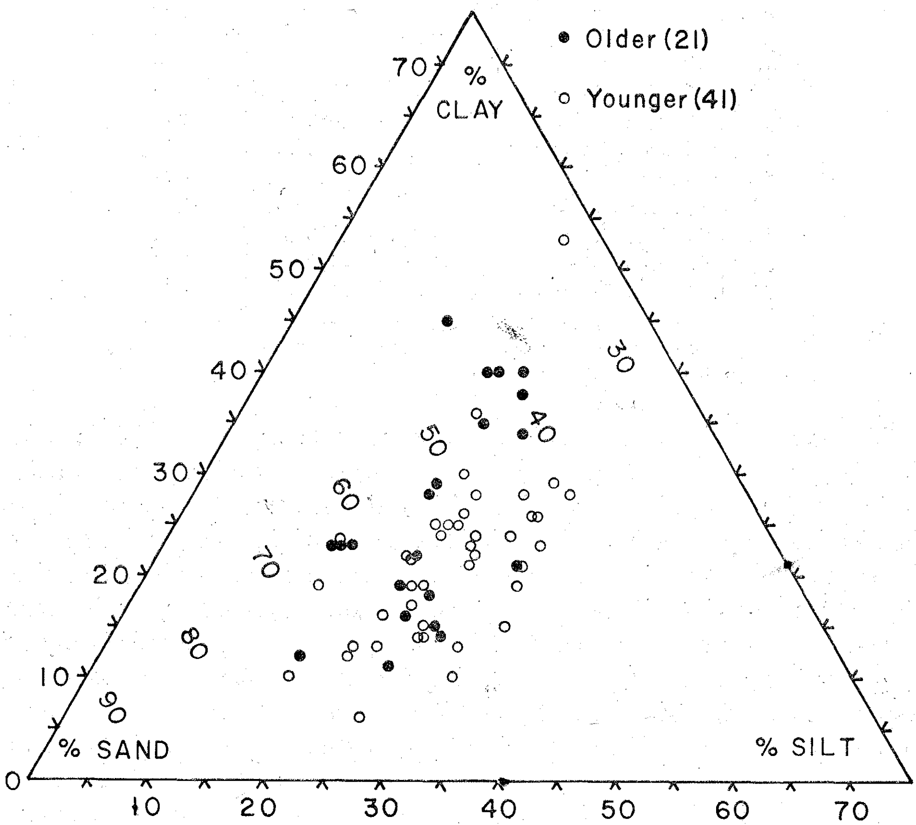



Fig. 2. Truncated ternary diagram showing percent sand, silt, and clay (scale of Wentworth, 1922) in the less-than-2-mm fractions of cove-deposit samples. Open circles represent samples of younger deposits and solid circles represent samples of older

## SEDIMENTOLOGICAL MEASUREMENTS

Figure 2 shows the results of the particle-size analyses. Most samples fall into the clay loam, loam, sandy clay loam, and sandy loam classifications. The solid circles are samples from cove deposits classified (on the basis of topography and weathering characteristics) as old. The open circles are samples either from cove deposits classified as young or from sideslope or headslope colluvium (these sites showed no apparent sedimentological differences and so have not been distinguished in the analyses). Note that there is a tendency for the old samples to have a higher percent of clay than do the younger ones, but the difference is slight. Boulders and cobbles make up a sizeable part of the deposits, but time did not allow the size distribution of this fraction to be determined.

Table I

Pebble-roundness measurements

| Site No. | Type deposit | Distance from crest | Mean roundness |
|---|---|---|---|
| 1A | Cove deposit | 1100 m | 1.60 |
| 1A | Modern alluvium | 1100 m | 4.56 |
| 4M | Cove deposit | 2050 m | 3.72 |
| 4M | Modern alluvium | 2050 m | 2.96 |
| 5A | Cove deposit | 750 m | 1.72 |
| 5A | Modern alluvium | 750 m | 1.72 |
| 4L | Modern alluvium | 1150 m | 1.52 |
| 5B | Cove deposit | 1430 m | 1.60 |
| 7A | Sidewall colluvium | 1110 m | 1.40 |

Clasts were mostly gneiss and schist in composition, except at 7A where they were all from the Longarm Quartzite.

The results of pebble-roundness measurements are shown in Tab. I. At sites 1A, 4M, and 5A (Fig. 1), pebble samples from modern streams adjacent to the fan (or cove) sites were collected in order to allow a comparison between the diamictons and alluvium with a similar distance of travel. Only site 1A showed the expected results, the mean roundness of the alluvial pebbles being much higher than that of the fan pebbles. At sites 4M and 5A, however, the fan deposits were as round or rounder than the alluvial deposits. This result probably arises from the fact that the streams are rapidly incising the fans (perhaps partly in response to clearing of the forest), so that much new sediment is being supplied to the stream along their courses, thereby obscuring any stream-induced rounding.

Note that with the exception of site 4M, all the fan pebble samples are angular. Site 4M is a matrix-poor deposit near the distal end of a fan where fluvial transport and deposition probably were somewhat more important than farther upslope. Note that the sample from site 7A, located in sidewall colluvium, had the most angular clasts. However, this angularity may very well have derived from the quartzose composition of the clasts.

Schmidt nets of the 11 fabric sites are shown in Fig. 3. The nets have been rotated so that in each case the downslope direction is toward the bottom of the page. Two of the sites are sideslope or headslope (5A and 7A), the remainder being young cove deposits. Note that although fabric strength varies greatly, the preferred alignment of the long axes is in all cases approximately parallel to slope and that in the majority of cases the mode is in the downslope rather than in the upslope direction.

The numerical analyses, together with slope angle, slope orientation, and percent silt and clay, are presented in Tab. II. The calculated $V_1$ orientations and dips support the inferences drawn from inspection of the Schmidt nets. Note that all $V_1$ orientation values correspond closely to the slope orientation (or to the latter value plus or minus 180°), the maximum deviation of the $V_1$

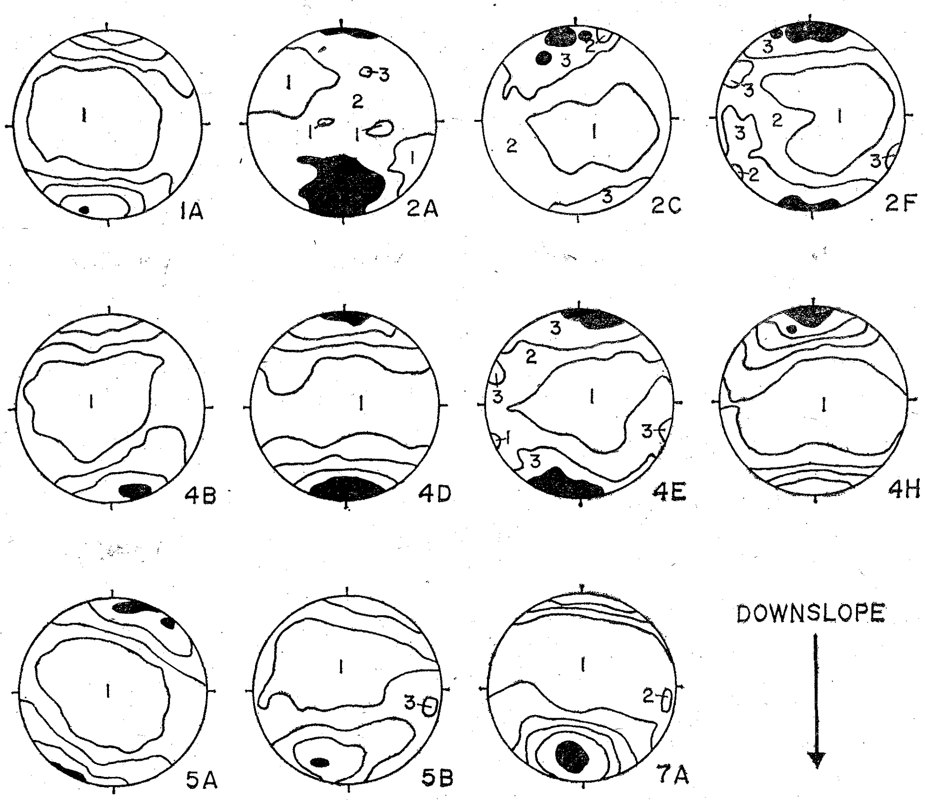



Fig. 3. Equal-area Schmidt nets for all fabric sites. Nets have been rotated so that the downhill direction is toward the bottom of the page in all cases. Contouring was done by the method of KAMB (1959) at intervals of two standard deviations. The areas numbered 1 are those of least density, with higher numbers indicating greater density; black areas are those of greatest density on each net

Table II

Fabric measurement results

| Site No. | No. clasts | Slope angle | Slope ort * | $V_1$ ort | $V_1$ dip | $S_1$ | $V_3$ ort | $V_3$ dip | $S_3$ | L % | % silt | % clay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1A | 50 | 10° | 100° | 111° | 07° | 0.615 | 227° | 74° | 0.073 | 34.6 | 23 | 19 |
| 2A | 50 | 18° | 045° | 065° | 19° | 0.438 | 165° | 24° | 0.250 | 22.7 | 23 | 25 |
| 2C | 25 | 08° | 040° | 207° | 16° | 0.525 | 344° | 68° | 0.158 | 23.9 | 15 | 19 |
| 2F | 50 | 11° | 060° | 062° | 01° | 0.469 | 331° | 66° | 0.156 | 9.6 | — | — |
| 4B | 50 | 24° | 060° | 047° | 09° | 0.547 | 166° | 70° | 0.138 | 27.9 | 30 | 26 |
| 4D | 50 | 15° | 012° | 011° | 05° | 0.620 | 267° | 71° | 0.152 | 44.6 | 21 | 13 |
| 4E | 50 | 12° | 062° | 063° | 01° | 0.512 | 329° | 77° | 0.173 | 25.6 | 24 | 25 |
| 4H | 50 | 20° | 050° | 227° | 07° | 0.670 | 340° | 73° | 0.088 | 48.2 | 21 | 22 |
| 5A | 50 | 23° | 186° | 033° | 04° | 0.579 | 252° | 85° | 0.095 | 28.0 | 23 | 17 |
| 5B | 50 | 18° | 147° | 154° | 24° | 0.537 | 305° | 63° | 0.152 | 20.9 | 28 | 28 |
| 7A | 33 | 25° | 120° | 131° | 25° | 0.729 | 330° | 64° | 0.066 | 49.6 | 24 | 28 |

* ort is abbreviation for orientation.
The $p \leq 0.05$ significance level for $S_1$ is 0.512 (n = 25) or 0.460 (n = 50); for $S_3$ it is 0.169 (n = 25) or 0.216 (n = = 50); for L % it is 34 (n = 25) or 24 (n = 50)

orientation from the line of slope being 27° and the mean deviation being only 9.9°. In addition, note that of the 11 $V_1$ orientation values, 8 are in the downslope direction. The $V_1$ dip values, however, show that upslope imbrication is the rule (if by upslope imbrication is meant a preferred dip less than that of the slope angle), for of the 8 samples showing a preferred downslope alignment, 5 have a $V_1$ dip less than the slope angle, 2 have a $V_1$ dip greater than the slope angle, and 1 has a $V_1$ dip equal to slope angle. Hence, of the 11 sites, 8 show an upslope imbrication.

As shown by the values of $S_1$, $S_3$, and L%, there is a wide range in clast strength. Some of the $S_1$ values compare favourably with till-fabric values (e. g. Mark, 1974; Mills, 1977); others are somewhat weaker. Of the 11 samples, 10 had significant $S_1$ and $S_3$ values and 7 had significant L% values. Concerning possible effects of slope angle and texture on fabric strength, no significant correlations were found. Similarly, these variables also showed no correlation with $V_1$ or $V_3$ dip angles.

## WEATHERING MEASUREMENTS

As discussed previously, the maximum percent clay, the reddest hue, and the percent weathered clasts were determined at each site as an index of weathering. In Fig. 4 the interrelationships of these three indices are presented by means of scatter plots for each of the three possible combinations. All three plots show significant correlations, although by far the strongest is that between hue and percent weathered clasts ($r = -0.806$). The fact that correlations between the weathering indices are significant supports the concept that they actually do reflect degree of weathering.

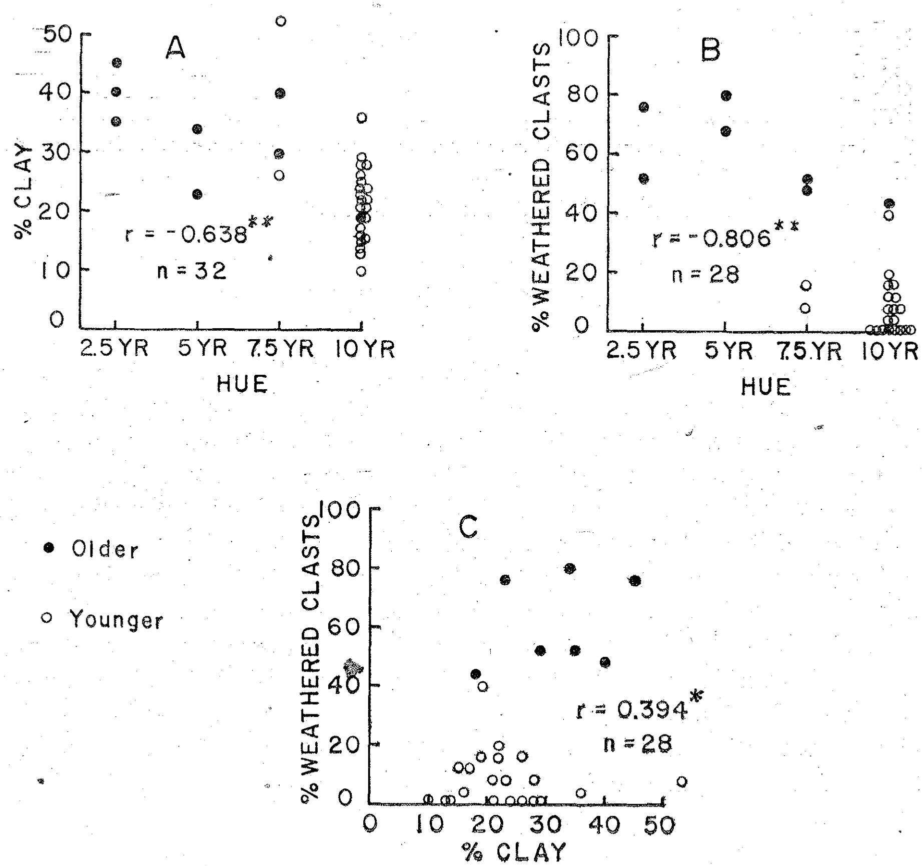



Fig. 4. Interrelationships between the weathering indices maximum percent clay, reddest hue (Munsell notation, where 2.5 YR is most red and 10 YR is least red), and percent weathered clasts. One asterisk indicates p ⩽ 0.05, two asterisks indicate p ⩽ 0.01. Open circles represent younger sites, solid circles represent older

One of the major purposes of measuring indices at a number of sites, of course, was to determine whether the deposits could be divided into discrete groups on this basis. In Fig. 4, open circles again represent young sites and solid circles oldones. These plots, particularly plot A (percent weathered clasts vs. hue), suggest that the old and young sites do form two discrete groups. The young sites appear to be fairly homogeneous, as most have 10 YR hues and less than 20% weathered clasts. The range of percent clay is wide, although clearly tends to be lower than in the old sites. The old sites, in contrast, are quite heterogeneous, suggesting that they comprise more than one age group.

In order to test objectively the apparent grouping of the sites, a discriminant analysis (KLECKA, 1975) was performed, using the variables percent clay, hue, and percent weathered clasts. A plot of the discriminant-fuction score for each site is presented in Fig. 5; solid squares represent older sites and open squares represent younger sites. Note that discrimination is perfect in that a score exists

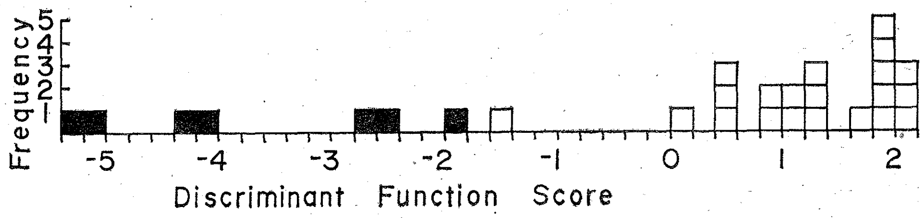



Fig. 5. Frequency distribution of scores on discriminant function. Open squares represent younger sites, solid squares represent older

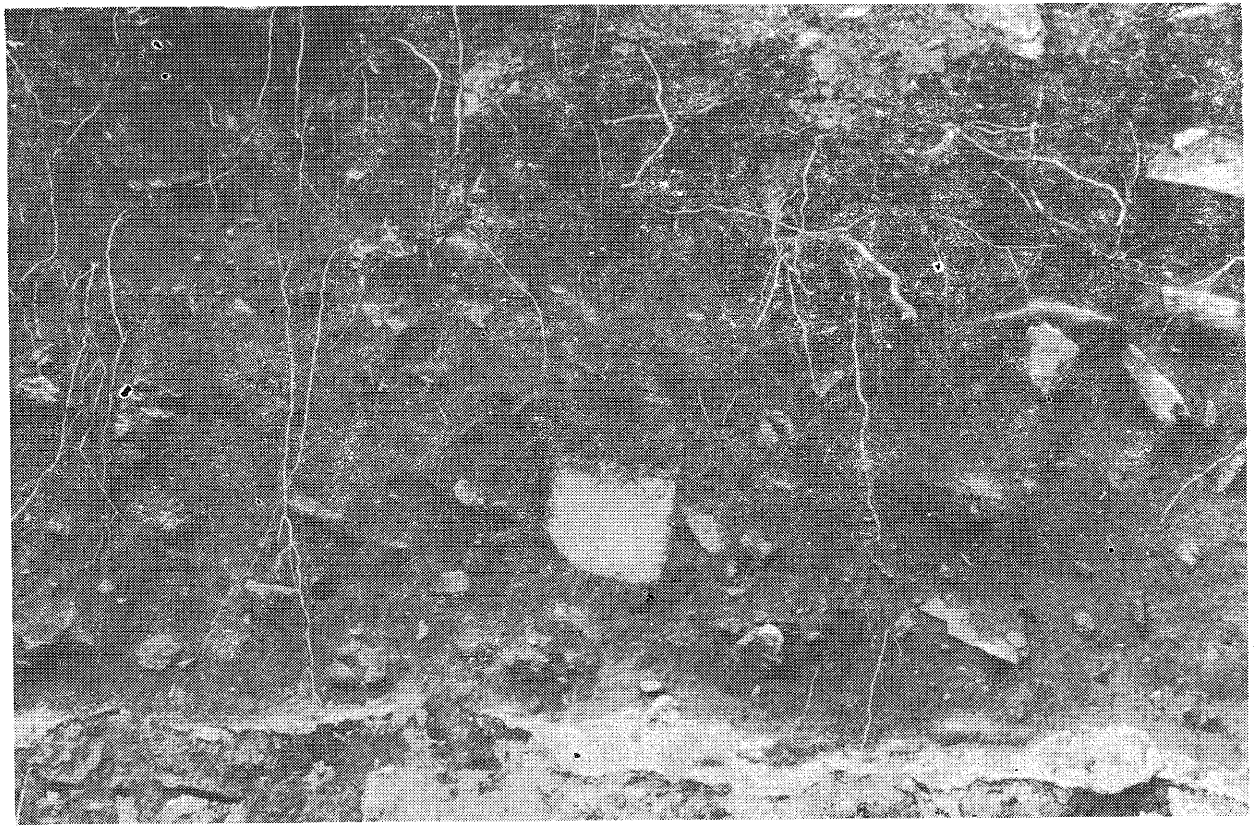
above which all younger sites lie and below which all older sites lie. More importantly, however, there appears to be a distinct gap between the two groups, suggesting that there is indeed a time hiatus between the two. The one exception is site 2C, which is represented in Fig. 5 by the leftmost open block. It appears to group with the older sites, and thus apparently was misclassified. Interestingly, this site is located in an area mapped as "old" by HADLEY and GOLDSMITH (1963), but it appeared to me more closely resemble the young deposits. The discriminant analysis seems to bear out HADLEY and GOLDSMITH, however.

Standardized discriminant-function coefficient show the relative contribution of each variable to the discriminant function (KLECKA, 1975). These coefficients are as follows in the present analysis: percent clay, −0.153; hue −0.301; and percent weathered clasts −0.994. Hence, the latter is by far the most important variable in discriminanting between the two groups of sites.

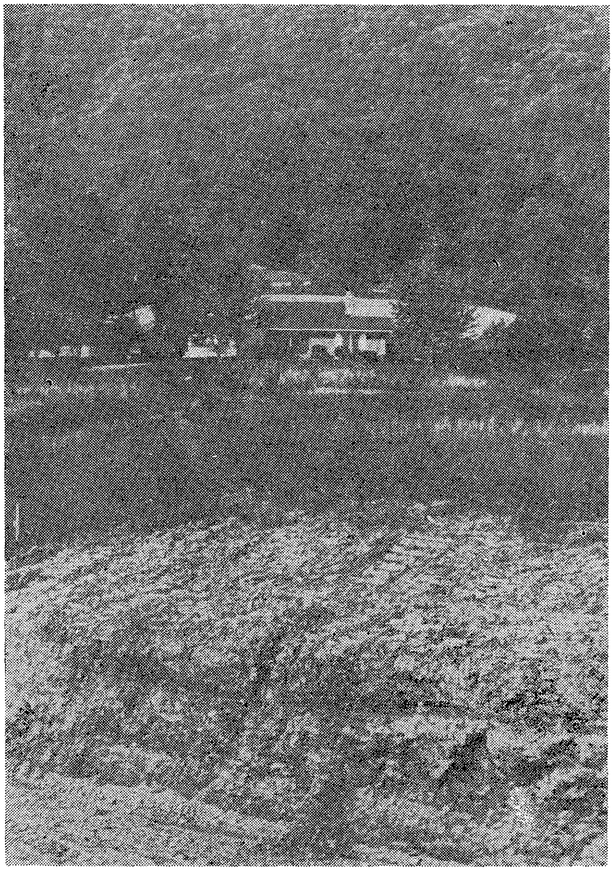
## DISCUSSION

Pollen evidence from the central and southern Appalachians suggests that the climate in this region was much colder during the last glacial maximum (e. g. WATTS, 1975, 1979; DELCOURT and DELCOURT, 1979), so that a former periglacial climate at the higher elevations in the Dellwood quadrangle appears quite possible. Further evidence of such an environment is provided by CLARK'S (1968) observations of patterned ground far south as southern Virginia. The question remains, however, of whether, aside from MICHALEK'S (1968) observations on latitudinal and altitudinal distributions, evidence exists to show that piedmont-cove deposits are produced during times of glacial climates.

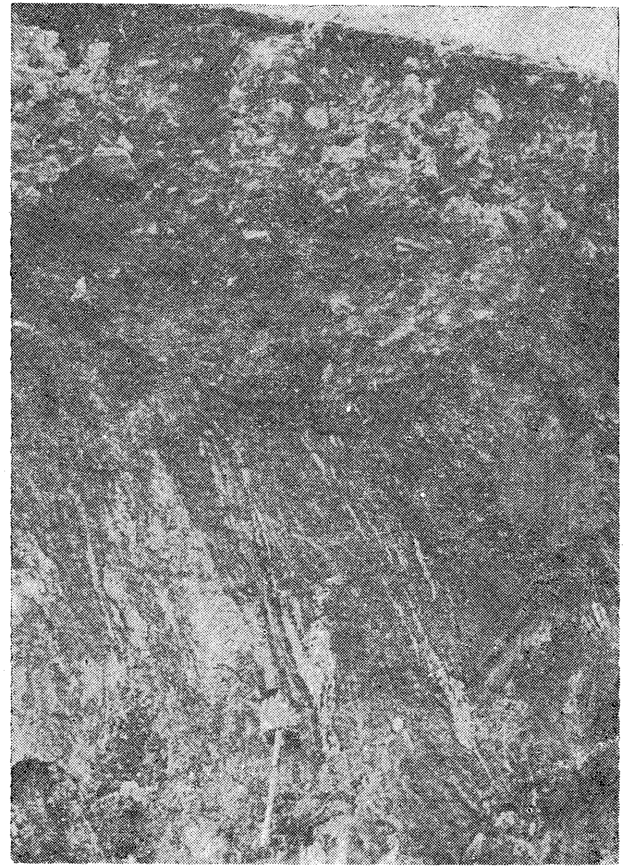
One way to demonstrate this would be to find evidence that periglacial processes, such as gelifluction, were involved in the deposition of the cove sediments. The sedimentological data, however, provide inadequate evidence for such an intepretation. The textural and roundness data support the concept that the deposits are the product of mass movements, but there is little evidence to favour gelifluction rather than debris flows. Of the nine features listed by BENEDICT (1976) as properties of gelifluction, the cove deposits lacked any sign of gelifluction lobes or similar topographic configurations. In addition, there



Pl. 1. Exposure of nonsorted, unstratified deposits with angular clasts, typical of smaller fans and upper parts of larger fans. Cut is about 1.5 m high



Pl. 2. Site 2E in Germany Cove. Excavation reveals highly weathered older fan deposit. Background shows surface of fan, looking upslope



Pl. 3. Site 5 G. Channel incised into saprolitized gneiss and filled with relatively unweathered diamicton. Shovel is 53 cm long

was no indication of crude sorting or stratification (except in the deposits that were clearly partly fluvial in nature), no platy soil structure, no mottling, and no buried organic matter (of course, such features may have been destroyed by weathering and erosion in the thousands of years since cessation of a glacial climate). On the positive side, the younger deposits, at least, are located in lower areas that would tend to be moister, the silt content of the deposits is fairly high, and most rock fragments are angular. None of these three characteristics, however, is at all distinctive.

The fabric results were ambiguous. Fabric patterns supposedly typical of gelifluction were observed, but many of the fabrics were not as strong as gelifluction fabrics are reputed to be. A particularly bothersome problem is the lack of fabric studies on modern coarse debris flows, which makes the use of fabric to distinguish gelifluction from debris flows nearly impossible. Hence, although the fabrics support the concept of downslope mass movement, they give little indication as to what type of mass movement was involved.

The existence of huge boulders on the surface of the fans has also been cited as evidence for gelifluction (e. g. MICHALEK, 1968). However, as Hurricane Camille showed, most of these boulders could have been transported by debris flows, and the very largest might be "letdown erratics" (LANDES, 1959). The gelifluction hypothesis suffers further because of the lack of other features besides gelifluction indicative of periglacial conditions, such as involutions and patterned ground, in the fan area. On the whole, therefore, my opinion is that debris flow (combined to some extent with normal fluvial deposition on the distal parts of larger fans) rather than gelifluction is more likely to have been the mechanism that built the fans, although the evidence does not eliminate gelifluction as a possibility.

To say that gelifluction was probably not responsible for the fans does not necessarily mean, however, that the fans are not the product of climatic change. Indeed, several authors have reported alluvial fans which seem to have been active during the late Wisconsin or early Holocene, but which for the most part have undergone dissection since that time (HOPLEY, 1973; FUNK and DORT, 1977; WASSON, 1977). A debris-flow origin is, in fact, quite compatible with a model of landscape response to Quaternary climatic change that has been suggested by DELCOURT (1980a, 1980b) for the southern Appalachians. According to this model, great quantities of debris are produced by frost action at higher elevations during times of glacial climates. Massive transfer of this material downslope to lower elevations, however, does not take place until climatic amelioration occurs (evidence for this is provided by the fact that streams draining the higher mountains undergo degradation during glacial times and aggradation during interglacial and interstadial times). At the transition from lateglacial to interglacial times, it is known from pollen data that both temperature and absolute precipitation increased. Although direct evidence does not exist, it may be that the latter increase was accompanied by an increase in the frequency of catastrophic rainstorms, similar to the 1969 Hurricane Camille deluge in central Virginia.

Such a storm acting upon the accumulated products of thousands of years of frost action at higher elevations could produce debris flows of gargantuan size. In addition, the presence of large amounts of unstable debris would lower the intensity of rainfall required to initiate debris flows. Under such conditions, considerable thicknesses of piedmont-cove deposits could be built up in a relatively short period of time.

Although by no means conclusive, the field evidence suggests that the cove deposits may very well have accumulated in this fashion. Consider the "young" cove deposits. According to Delcourt's model, these deposits probably date from the early Holocene. The degree of weathering and soil formation observed on these deposits appears roughly equivalent to that of late Wisconsin glacial deposits in the northeastern and northcentral United States, so that an early Holocene age seems reasonable on this basis. The fact that the young cove deposits appear to be homogeneous in their weathering characteristics suggests that they were deposited within a relatively short period of time (say, several thousand years), which also is compatible with the model. The apparent hiatus in time between these deposits and the older ones likewise is compatible, for little deposition on the fans would have taken place during the glacial climates of the late Wisconsin, so that the next youngest deposits to occur in any abundance would be mid-Wisconsin or older in age.

The possibility must be considered, of course, that the piedmont-cove fans may be the result of catastrophic floods randomly spaced through time during the Quaternary, unrelated to climatic regime. This would mimic climatic control by also resulting in episodic deposition, and if the recurrence interval of such floods were somewhat greater than the 1,000 years suggested by THOMPSON (1969), weathering differences might distinguish successive deposits. According to this hypothesis, however, the great volumes of "young" cove deposits, because of the similar degree of weathering shown by these deposits, would have to be either the product of a single flood, or else that of multiple floods closely grouped in time. Concerning the first possibility, under present conditions it seems inconceivable that a single flood could move the huge volumes of young debris present on the fans; the volume moved by the Hurricane Camille floods, the most intense ever observed in the Appalachians, was only a tiny fraction of the volume of young deposits on the Dellwood fans. Concerning the second possibility, it seems improbable (though, of course, mathematically possible) that a clustering of debris flows in time would occur by chance alone. Rather, it seems more likely that special circumstances, such as those that prevailed during the lateglacial-interglacial transition (increased precipitation and the presence of abundant unstable debris at higher elevation), caused such grouping. These conditions would also have made possible much larger individual debris flows than those which occur today.

The "old" deposits on the fans vary greatly in their degree of weathering, and therefore probably represent more than one depositional episode. By comparison with the degree of weathering shown by glacial deposits of known age in the northeastern and north-central United States, these deposits probably range in age from mid-Wisconsin to Illinoian or even pre-Illinoian.

## CONCLUSIONS

A study of sedimentary structures, texture, pebble-roundness, and clast fabric suggest that the bulk of the piedmont-cove deposits in the Dellwood quadrangle were emplaced by mass-movement processes. However, there is little evidence to support the concept that gelifluction was the agent of transport. Although gelifluction cannot be ruled out as a possibility, debris flow seems a more likely transport mechanism.

The cove deposits may nonetheless be related to Quaternary climatic change. A discriminant analysis based on weathering indices shows that the younger cove deposits are separated from the older ones by a hiatus in degree of weathering, and thus presumably also in time. As the weathering characteristics of the younger deposits are compatible with an early Holocene age, it seems quite possible that they were laid down during the Pleistocene—Holocene transition by debris flows which were produced by a combination of increased precipitation and the presence of large volumes of unstable periglacial debris. Conclusive proof, however, must await absolute dating of the deposits.

## References


BENEDICT, J. B., 1970 — Downslope soil movement in a Colorado alpine region: rates, processes, and climatic significance. *Arctic and Alpine Res.*, 2; p. 165—226.

BENEDICT, J. B., 1976 — Frost creep and gelifluction features: a review, *Quatern. Res.*, 6; p. 55—76.

BROCHU, M., 1978 — Disposition des fragments rocheux dans les dépôts de solifluxion, dans les éboulis de gravité et dans les dépôts fluviatiles. *Biuletyn Peryglacjalny*, 27; p. 35—51.

BURKE, R. M. and BIRKELAND, P. W., 1979 — Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California. *Quatern. Res.*, 11; p. 21—51.

CLARK, G. M., 1968 — Sorted patterned ground: new Appalachian localities south of the glacial border, *Science*, 161; p. 355—356.

CURRAY, J. R., 1956 — The analysis of two-dimensional orientation data. *Jour. Geol.*, 64; p. 117—131.

DELCOURT, P. A., 1980a — Quaternary alluvial terraces of the Little Tennessee River Valley, east Tennessee, *in*: Chapman, Jefferson: The 1979 archaeological and geological investigations in the Tellico Reservoir. *Univ. Tennessee. Dept. Anthrop. Rep. Invest.*, 29; p. 110—121.

DELCOURT, P. A., 1980b — Landscape response to Quaternary climatic change in east Tennessee. *Geol. Soc. Amer., Abs. w. Programs*, 12; p. 411.

DELCOURT, P. A. and DELCOURT, H. R., 1979 — Late Pleistocene and Holocene distributional history of the deciduous forest in the southeastern United States. *Veröff. Geobot. Inst. ETH, Stiftung Rübell, Zürich*, 68; p. 79—107.

Denny, C. S., 1956 — Surficial geology and geomorphology of Potter County, Pennsylvania. *U. S. Geol. Surv., Prof. Paper* 288; 72 p.

Funk, J. M. and Dort, W., Jr., 1977 — Quaternary climatic effects on alluvial-fan systems, Birch Creek Valley, east-central Idaho. *Geol. Soc. Amer., Abs. w. Programs*, 9; p. 982—983.

Gryta, J. J. and Bartholomew, M. J., 1977 — Evidence for late Cenozoic debris-avalanche type deposits in Watauga County, North Carolina. *Geol. Soc. Amer., Abs. w. Programs*, 9; p. 142—143.

Hack, J. T., 1965 — Geomorphology of the Shenandoah Valley, Virginia and West Virginia, and origin of the residual ore deposits. *U.S. Geol. Surv., Prof. Paper* 484; 83 p.

Hack, J. T. and Goodlett, J. C., 1960 — Geomorphology and forest ecology of a mountain region in the central Appalachians. *U. S. Geol. Surv., Prof. Paper* 347; 66 p.

Hadley, J. B. and Goldsmith, R., 1963 — Geology of the eastern Great Smoky Mountains, North Carolina and Tennessee. *U.S. Geol. Surv., Prof. Paper* 349-B; 118 p.

Hamilton, W., 1961 — Geology of the Richardson Cove and Jones Cove quadrangles, Tennessee. *U.S. Geolog. Surv., Prof. Paper* 349-A; 55 p.

Hopley, D., 1973 — Geomorphic evidence for climatic change in the late Quaternary of northeast Queensland, Australia. *Jour. Tropical Geogr.*, 36; p. 20—30.

Kamb, W. B., 1959 — Ice petrofabric observations from Blue Glacier, Washington, in relation to theory and experiment. *Jour. Geophys. Res.*, 64; p. 1891—1904.

King, P. B., 1964 — Geology of the central Great Smoky Mountains, Tennessee. *U.S. Geol. Surv., Prof. Paper* 349-C; 148 p.

Kirby, R. P., 1967 — The fabric of head deposits in south Devon. *Proc. Ussher Soc.*, 1; p. 288—290.

Klecka, W. R., 1975 — Discriminant analysis. *In:* Nie, N. H. and others, Statistical Package for the Social Sciences. New York, McGraw Hill; p. 434-467.

Krumbein, W. C., 1939 — Preferred orientation of pebbles in sedimentary deposits. *Jour. Geol.*, 47; 673—706.

Krumbein, W. C., 1941 — Measurement and geological significance of shape and roundness of sedimentary particles. *Jour. Sed. Petrology*, 11; p. 64—72.

Landes, K. K., 1959 — Erratics through letdown, western Alberta, Canada (Abs.). *Geol. Soc. Amer. Bull.*, 70; p. 1634—1635.

Lindsay, J. F., 1968 — The development of clast fabric in mudflows. *Jour. Sed. Petrology*, 38; p. 1242—1253.

Mark, D. M., 1973 — Analysis of axial orientation data, including till fabrics. *Geol. Soc. Amer. Bull.*, 84; p. 1369—1374.

Mark, D. M., 1974 — On the interpretation of till fabrics. *Geology*, 2; p. 101—104.

Michalek, D. D., 1968 — Fanlike features and related periglacial phenomena of the southern Blue Ridge. Ph. D. dissert., Univ. North Carolina, Chapel Hill, North Carolina; 198 p.

Miller, C. D., 1979 — A statistical method for relative-age dating of moraines in the Sawatch Range, Colorado. *Geol. Soc. Amer. Bull.*, 90; p. 1153—1164.

Mills, H. H., 1977 — Basal till fabrics of modern alpine glaciers. *Geol. Soc. Amer. Bull.*, 88; p. 824—828.

Mills, H. H., 1982 — Piedmont-cove deposits of Dellwood quadrangle, Great Smoky Mountains, U.S.A.: morphometry. *Ztschr. f. Geomorph.*, 26; p. 163—178.

Ryder, J. M., 1971 — The stratigraphy and morphology of paraglacial alluvial fans in south-central British Columbia. *Can. Jour. Earth Sci.*, 8; p. 279—298.

Scheidegger, A. E., 1965 — On the statistics of the orientation of bedding planes, grain axes, and similar sedimentological data. *U.S. Geol. Surv., Prof., Paper* 525-C; p. C164—C167.

THOMPSON, H. J., 1969 — The James River flood of August 1969 in Virginia. *Weatherwise*, October, 1969; p. 180—183.

WASHBURN, A. L., 1980 — Geocryology. New York, John Wiley & Sons; 406 p.

WASSON, R. J., 1977 — Last-glacial alluvial fan sedimentation in the lower Derwent, Tasmania. *Sedimentology*, 24; p. 781—799.

WATTS, W. A., 1975 — Vegetation record for the last 20,000 years from a small marsh on Lookout Mountain, northwestern Georgia. *Geol. Soc. Amer. Bull.*, 86; p. 287—291.

WATTS, W. A., 1979 — Late Quaternary vegetation of central Appalachia and the New Jersey coastal plain. *Ecol. Monographs*, 59; p. 427—469.

WENTWORTH, C. K., 1922 — A scale of grade and class terms for clastic sediments. *Jour. Geol.*, 30; p. 377—392.

WILLIAMS, G. P. and GUY, H. P., 1973 — Erosional and depositional aspects of Hurricane Camille in Virginia, 1969. *U.S. Geol. Surv., Prof. Paper* 804; 80 p.

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