CLAST FABRIC IN RELICT PERIGLACIAL COLLUVIUM, SALAMANCA RE-ENTRANT, SOUTHWESTERN NEW YORK, USA

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ABSTRACT. Samples of macrofabric data obtained from colluvial deposits near the late-Wisconsinan glacial margin display widely divergent characteristics. Those from highly weathered and jointed sandstone plot as girdle distributions. Samples from red colluvium of early-Wisconsinan age form moderately strong clusters. Fabrics from shallow depth in medium-textured brown colluvium of late-Wisconsinan age generally have modes aligned with the local slope but are weak, and appear to have been modified by frost heaving. Clasts in the basal layers of an overlying loess unit were emplaced by frost heaving from the brown colluvium and have very weak or uniform fabrics. Particle shape exerts an influence on fabric strength in the brown colluvium, with samples composed of more elongated clasts displaying stronger fabrics. Fabrics from near-surface deposits show generally weaker shape and strength characteristics and higher inclinations than those at depth. Calculated seasonal frost penetration is consistent with the depth to which weaker, more steeply inclined fabrics are found. Sampling in relict periglacial deposits should be performed only below the level of disturbance by seasonal frost.

Key words: clast fabric, colluvium, eigenvalues, frozen ground, mass movement, New York, periglacial environment, permafrost, solifluction, spherical statistics, sampling.

Introduction

Hillslope deposits can play a critical role in understanding the interrelation between climate change, sediment transfer, and landform development (Pederson *et al.* 2000). Many unglaciated parts of the eastern United States are blanketed with sediments deposited by mass-movement processes typically ascribed to periglacial climatic conditions (Denny 1956; Ciolkosz *et al.* 1986; Mills 1987). This “frost mantle” could, however, have been emplaced by any or a combination of several mechanisms, including debris flows, frost creep, and solifluction. Several morphological, microenvironmental, and sedimentological characteristics can be used to infer the dominant transport mechanism responsible for such deposits. The orientation of large clasts embedded in a finer matrix, commonly referred to as *macrofabric*, has been used as one such criterion (Nelson 1985; Fitzsimons 1990; Nieuwenhuijzen and Van Steijn 1990; Mills 1991; Bertran *et al.* 1997).

Solifluction is a combination of gravity flow and seasonal creep processes (Washburn 1980; Harris 1981; Williams 1982). Both field (Nelson 1985; Yamamoto 1989) and laboratory (Bertran 1993) research demonstrate that solifluction can generate highly clustered macrofabrics, indicating that fabric analysis has considerable potential as a tool for identifying the genesis of hillslope deposits. Clasts within other flow phenomena, such as debris flows, show less pronounced downslope orientation (Lawson 1979; Mills 1984, 1991; Bertran *et al.* 1997). Partly on this basis, a solifluction origin has been proposed for some colluvial deposits in the United States (Ciolkosz *et al.* 1986; Mills 1987) and in Europe (Kirby 1967; Watson and Watson 1970; King 1972). Although clast fabric is an important component of interpretative procedures, a multiple-criteria approach is essential for unambiguous identification of colluvium as solifluction deposits (Benedict 1976; Nelson 1985). This is of particular significance considering that macrofabrics in relict periglacial deposits do not commonly exhibit the strong downslope clustering found in active solifluction deposits (Benedict 1970; Nelson 1985; Yamamoto 1989). If macrofabrics are to play a useful role in paleoenvironmental research (cf. Bennett *et al.* 1999) such disparities must be explained. Several problems exist with the use of macrofabric analysis in this context:

(1) Sampling strategies are rarely uniform between studies. The morphology and orientation of sampling surfaces, often determined by the location of pre-existing exposures, can af-

fect fabric strength profoundly, as can the details of data-collection procedures (Millar and Nelson 2001). Comparative studies of fabrics from deposits emplaced by different hillslope processes may be severely hampered by the lack of standardized methods of data collection employed by different investigators.

(2) Little research has been conducted on fabrics in contemporary solifluction features. The availability of such work would enable comparison with fabrics from colluvium of possible periglacial origin in the mid-latitudes. Bertran and Texier (1999) have emphasized the necessity for such comparative studies. Recent work in Alaska (Millar, unpublished data) indicates that the strong downslope orientation typically associated with solifluction (e.g. Nelson 1985) may be limited to localized microenvironments conducive to the development of highly clustered fabric patterns.

(3) In regions formerly subject to solifluction processes (including the eastern United States), penetration of seasonal frost may disrupt fabric patterns. Repeated episodes of frost heaving are known to reorient elongate clasts into more vertical configurations (e.g. Fahey 1975; Washburn 1980).

In this paper we address the concerns outlined above, with particular emphasis on the effects of frost, by examining macrofabrics from colluvium, previously identified as a paleoperiglacial deposit (Snyder and Bryant 1992), in the Salamanca Re-entrant of southwestern New York, immediately adjacent to the late-Wisconsinan glacial border.

Study area

General setting

The Salamanca Re-entrant of southwestern New York (Fig. 1) is situated on a northern extension of the Allegheny Plateau, and is underlain by the Cattaraugus and Oswayo Formations (Tesmer 1975) dipping to the southwest at approximately 6.5 m km^{-1} (Lytle 1965). Colluvium overlying weathered bedrock slopes consists of shale and sandstone clasts entrained in a generally silty matrix (Snyder 1988). Loess blankets much of the region with thicknesses up to 70 cm. Loess deposition commenced about 20 300 ±3000 yr BP, followed by a second period of significant accumulation between 14 000 and 10 000 yr BP (Snyder 1988, p. 64).

The Salamanca Re-entrant is defined by the position of the late-Wisconsinan southern glacial margin (Snyder 1988). The Re-entrant was surrounded on three sides by glacial ice as recently as 14 ka BP, and may have experienced cold and windy conditions similar to those of contemporary southwest Greenland (van Tatenhove and Olesen 1994; Duynkerke and van den Broeke 1994; van den Broeke *et al.* 1994). Many features indicative of a former periglacial environment have been reported in the region, including block fields (Smith 1953; Sevon 1990), sorted nets and sorted stripes (Denny 1956), solifluction deposits (Aguilar and Arnold 1985), pingo scars (Marsh 1987; Stone *et al.* 1992), stratified slope deposits, frost cracks, and soil wedges (Gardner *et al.* 1991), and grèzes litées and cryoplanation terraces (Clark and Ciolkosz 1988). A detailed study of pedogenic and landform relations (Snyder 1988; Snyder and Bryant 1992) concluded that two colluvial deposits within the immediate vicinity of the Re-entrant were emplaced under periglacial conditions. Given the proximity of the glacial border, the abundant regional evidence for periglacial conditions, palynological indications of tundra vegetation (Jacobson *et al.* 1987; Webb *et al.* 1987), and the strong local evidence for colluviation under periglacial conditions, it is highly probable that solifluction is among the processes responsible for the deposits in the Salamanca Re-entrant identified by Snyder and Bryant (1992) as paleoperiglacial colluvium.

Present-day environmental conditions are outlined in Table 1. Permafrost is not present, although seasonal frost affects soils in the area to depths of more than 0.5 m (U.S. Department of Agriculture 1941). The area of the Salamanca Re-entrant therefore provides an opportunity to assess the degree of surface reworking by present-day frost penetration, and its implications for interpretation of solifluction macrofabrics.

Site descriptions and field procedures

Two pits were excavated by backhoe in an open meadow on the north side of Bay State Brook Road in Allegany State Park (Fig. 1, Table 1). Soils in the vicinity were studied in detail by Snyder (1988) and Snyder and Bryant (1992); references to stratigraphic units are made with respect to these studies. Pit 1, located 100 m north of the road near Snyder's (1988, p. 45) Pit 5, is underlain by the Cattaraugus Formation. The 4.5×2.3 m pit was excavated to a depth of 1.5 m and penetrated weathered material derived from the Cattaraugus Formation. A stone

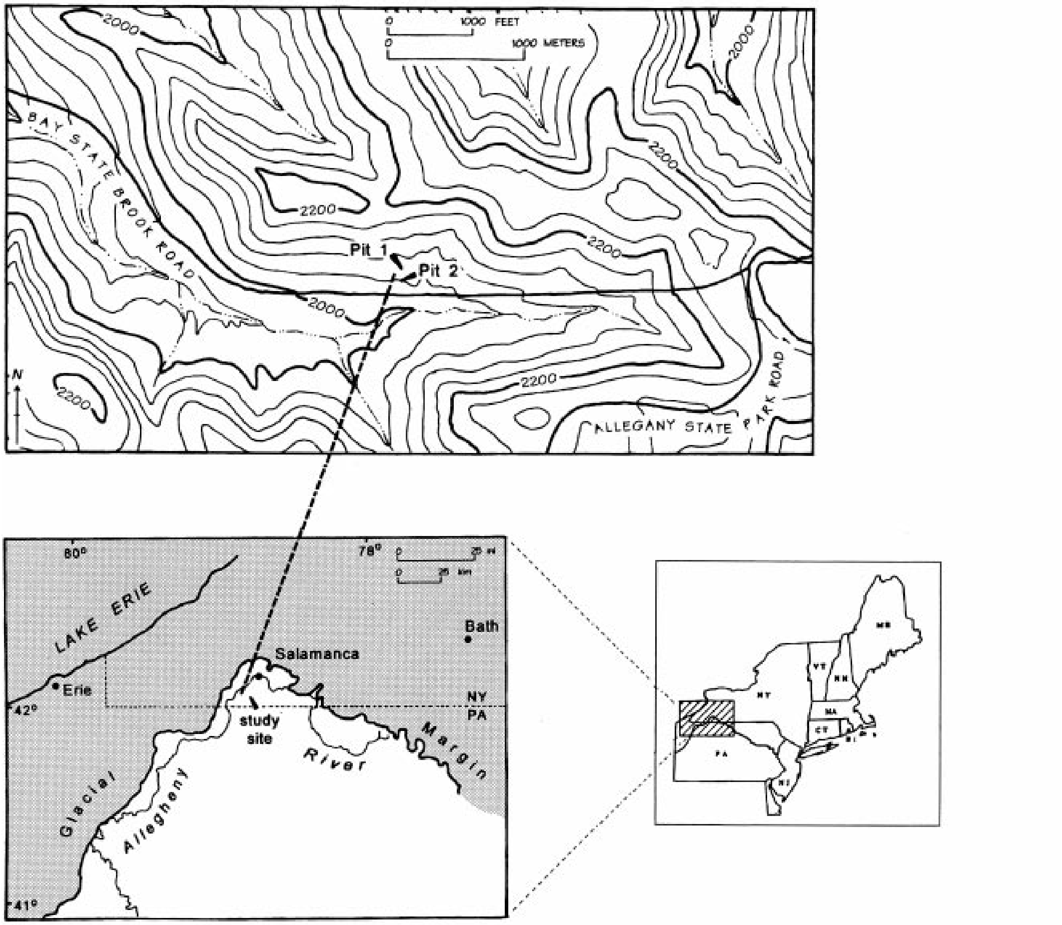

Fig. 1. Location of study area, showing approximate position of Late-Wisconsinan ice margin (modified from Snyder and Bryant 1992), local topography, and locations of Pits 1 and 2. Topography modified from USGS 7.5-minute, Red House, New York State topographic quadrangle (N4200-W7845/7.5).

line separates the weathered material from a small pocket of poorly sorted red colluvium. This undulose “red stringer colluvium” consists of weathered red-brown (Munsell 5YR 4/4; Kollmorgen Instruments Corporation 1988) shale derived from the Cattaraugus Formation and was interpreted by Snyder and Bryant (1992) as having been affected by cryoturbation in early-Wisconsinan(?) time. A medium-textured brown (10YR 5/4) colluvium nearly 1 m thick overlies the red colluvium. A stone line lies above the brown colluvium and separates it from the overlying Salamanca Loess (Snyder and Bryant 1992) at the top of the section. Thermoluminescence dates from the loess indicate a late-Wisconsinan age for the brown colluvium (Snyder and Bryant 1992).

Table 1. Site characteristics.

Geographic location	42°31'15"N, 78°46'58"W Cattaraugus County, New York
Land cover	Open field, vegetation includes herbs, forbs, and graminoids
Climate	Mean annual air temperature: 6.9°C Mean annual precipitation: 1085 mm
Bedrock	Cattaraugus and Oswayo Formations (Upper Devonian)
Pit 1	Local slope 14°, oriented S14°W; elevation 629 m
Pit 2	Local slope 07°, oriented S07°W; elevation 622 m

Pit 2 (4.9×2×1.8 m) was excavated downslope from Pit 1 at a distance of 50 m from Bay State Brook Road (Fig. 1, Table 1), adjacent to Snyder’s

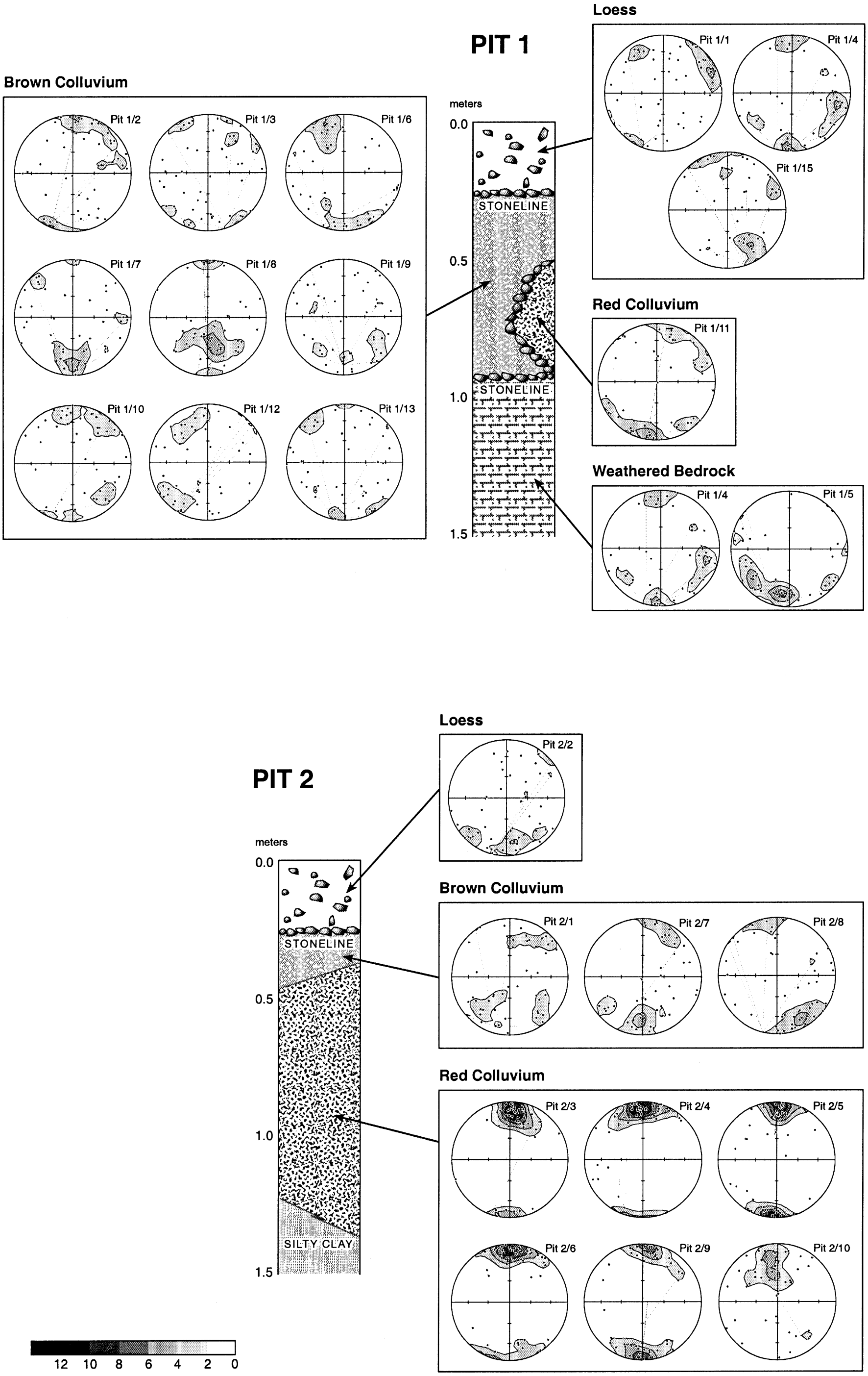

Fig. 2. Schmidt nets showing fabric data from Pit 1 and Pit 2 excavations at Allegany State Park. Approximate position of sampling locations within stratigraphic units is indicated. Contouring of point density distributions was implemented using Starkey's (1977) fixed-circle counting method, using counting circles occupying 100/*n* = 2% of the projected net (Stesky 1998). Shading density is standardized between plots and scaled to contour intervals representing 2, 4, 6, 8, 10, and 12 counts per 2% circle.

Table 2. Analytic results.

Sample	Depth (cm)	$\bar{\tau}_1$	$\bar{\tau}_2$	$\bar{\tau}_3$	γ	ζ	S_g*
1/01/L	20	0.221	0.318	0.461	1.035	0.734	10.93
1/02/B	36	0.179	0.283	0.538	1.401	1.099	25.53
1/03/B	31	0.231	0.296	0.473	1.878	0.714	11.66
1/04/W	122	0.132	0.380	0.488	0.239	1.301	24.81
1/05/W	152	0.046	0.370	0.584	0.219	2.543	55.09
1/06/B	31	0.145	0.287	0.568	1.007	1.362	34.67
1/07/B	31	0.181	0.324	0.495	0.725	1.007	18.57
1/08/B	31	0.167	0.197	0.636	6.877	1.341	51.83
1/09/B	31	0.260	0.316	0.425	1.581	0.492	5.32
1/10/B	61	0.140	0.319	0.541	0.644	1.348	30.16
1/11/R	76	0.121	0.275	0.604	0.965	1.604	45.57
1/12/B	31	0.175	0.351	0.474	0.434	0.995	16.89
1/13/B	51	0.181	0.344	0.475	0.508	0.963	16.25
1/14/L	20	0.200	0.331	0.469	0.690	0.858	13.74
1/15/L	20	0.181	0.345	0.474	0.488	0.961	16.11
2/01/B	38	0.214	0.313	0.473	1.082	0.796	12.88
2/02/L	25	0.177	0.314	0.509	0.842	1.055	20.82
2/03/R	51	0.058	0.094	0.848	4.565	2.681	149.21
2/04/R	31	0.026	0.187	0.787	0.722	3.421	120.58
2/05/R	94	0.079	0.163	0.758	2.114	2.260	102.58
2/06/R	91	0.077	0.136	0.787	3.118	2.319	116.29
2/07/B	31	0.111	0.302	0.587	0.667	1.661	42.92
2/08/B	31	0.149	0.281	0.570	1.122	1.338	34.65
2/09/R	97	0.083	0.154	0.763	2.584	2.220	104.85
2/10/R	122	0.168	0.212	0.620	4.569	1.308	46.70

See text for explanation of symbols. L, loess; B, brown colluvium; R, red colluvium; W, weathered bedrock.

* Test statistic for Mardia's (1972, p. 276) test of uniformity: $S_u = (15/2n) \sum_{i=1}^{3} (\tau_i - n/3)^2$

Critical value (0.05 level) for $n - 50$ is 11.07.

(1988, p. 44) Pit 4. Weathered bedrock was not encountered at the base of the excavation; rather a unit of gray (2.5YR 4/2) silty clay with low stone content was present at a depth of 1.7 m. This unit, probably the "paleosol colluvium" identified by Snyder (1988), was interpreted as a colluvial deposit incorporating blocks of pre-Wisconsinan soil. Approximately 1 m of red (5YR 4/4) colluvium overlies the clay, which in turn is overlain by brown (10YR 5/3) colluvium. Unlike the stratigraphy in Pit 1, a stone line is not apparent between the red and brown colluvium in Pit 2. A stone line separates the brown colluvium from overlying loess.

Fabric data were collected by measuring the A-axis azimuth and plunge of 50 elongate clasts at several locations on the vertical pit faces. Clasts were removed carefully and the orientation of a non-magnetic rod inserted into the resulting cavity was measured with a Brunton compass. A- B- and C-axis lengths were also recorded for each clast. Although no minimum A/B axial ratio requirement was applied to the clasts other than the obvious stipulation that A > B, the mean values of samples from the red and brown colluvial units fall within a fairly small range (approximately 1.4 to 1.7). Many different axial ratio limits have been used in previous studies (cf. Andrews and Smithson (1966) and Nelson (1985) with A/B = 2.0; Mills (1983) with A/B = 1.5; and Mills (1984) with A/B = 1.4).

Analytic procedures

Orientation data were plotted on lower-hemisphere Schmidt (equal area) nets and contoured using Starkey's (1977) point-counting method (Stesky 1998). Figure 2 shows Schmidt nets for samples from Pits 1 and 2, separated into their respective stratigraphic units. Following computational details in Mardia (1972) and Fisher *et al.* (1987), the eigenvectors of each sample were extracted from its "orientation matrix," a 3×3 array of the sums of squares and cross products of direction cosines from the individual observations. The eigenvectors t_i (i = 1, 2, 3) represent the mutually orthogonal axes of minimum, intermediate, and maximum clustering, respectively. The associated eigenval-

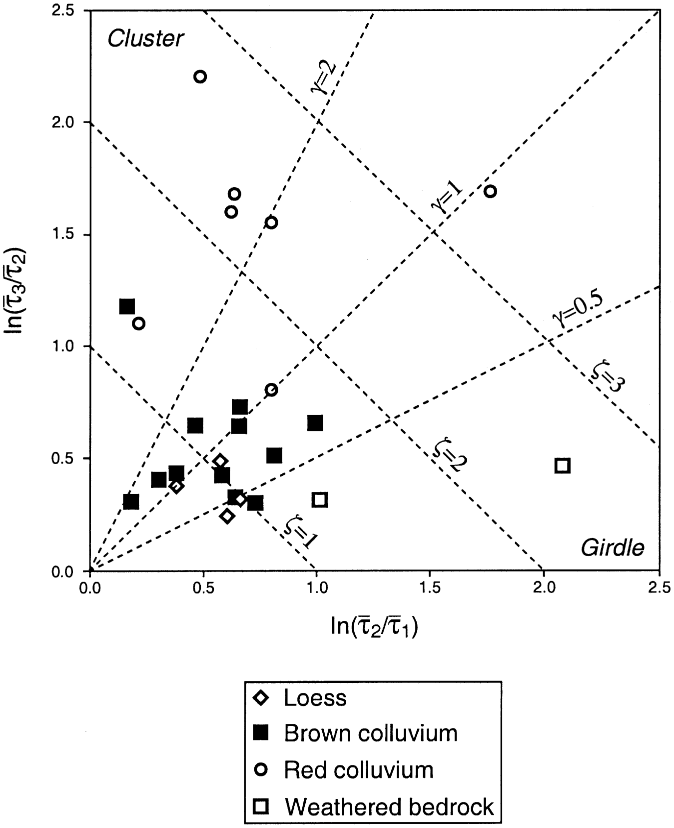

Fig. 3. Log-ratio plot (Woodcock 1977) comparing fabrics from stratigraphic units exposed in pits located in the Salamanca Re-entrant. Diagonal line, $\gamma = 1$, indicates position of transitional zone, above and below which lie clusters and girdles, respectively. Distance from origin is proportional to fabric strength. Symbols for axes, fabric strength, and fabric shape are explained in the text.

ues τ_i ($\tau_3 \geq \tau_2 \geq \tau_1$) indicate the degree of clustering around each of the axes (Table 2). By convention, the normalized eigenvalues $\bar{\tau}_i = \tau_i / n$ (where n = sample size) are reported in statistical summaries.

Woodcock (1977) developed a graphical method for comparing data sets based on ratios of the normalized eigenvalues, facilitating comparisons of the shape and strength of samples. Fabric data from the Salamanca Re-entrant are presented in this standard format in Fig. 3. A uniform distribution is described by three normalized eigenvalues of near-equal magnitude, and plots at the origin. Clustered distributions are indicated by large values of $\bar{\tau}_3$, plotting along the y-axis. Girdle distributions are represented by relatively large $\bar{\tau}_2$ and $\bar{\tau}_3$ values and correspondingly small $\bar{\tau}_1$. Girdles plot along the x-axis. Parameters describing the strength and shape of a sample are given by $\zeta = \ln(\bar{\tau}_3/\bar{\tau}_1)$ and $\gamma = \ln(\bar{\tau}_3/\bar{\tau}_2)/\ln(\bar{\tau}_2/\bar{\tau}_1)$, respectively (Fisher *et al.* 1987, p. 49).

Representation of data from Pits 1 and 2 on Schmidt nets reveals wide variation in fabric characteristics (Fig. 2). Figure 3 shows the position of each sample in Woodcock's (1977) eigenspace. Many of the samples plot as weak, transitional-type distributions. Half the samples from pit 2 (P2/3, 4, 5, 6 and 9) form moderately strong clusters. Comparison of Fig. 3 and Fig. 4 indicates that fabrics from well-defined solifluction features exhibit the highest degree of clustering (Nelson 1985). Clusters approaching the strength of those reported by Nelson (1985) were found exclusively in the red colluvium. The brown colluvium in both pits yielded transitional distributions showing similarities with fabrics from other mass-movement deposits, although the modes of most non-uniform samples are aligned subparallel with the local slope.

Discussion

Paleoenvironmental interpretation

Results presented in the previous section illustrate several problems involved with using fabric analysis to infer former periglacial slope processes. A

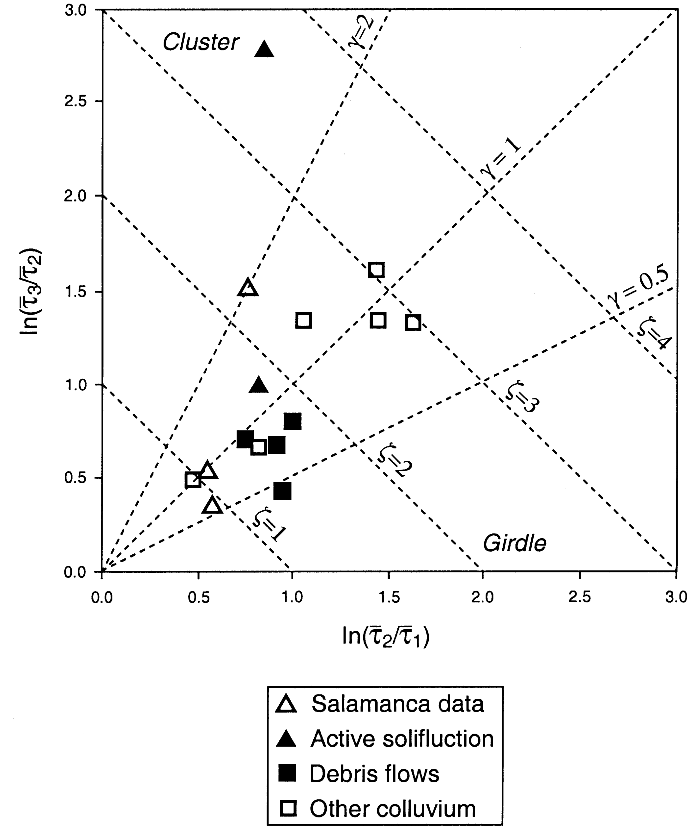

Fig. 4. Log-ratio plot comparing fabrics from various flow deposits. Salamanca data are average values for loess, brown colluvium, and red colluvium sampled for the present study. Fabric data from active solifluction features were collected near Eagle Summit, Alaska (Nelson 1985; Millar unpublished). Data for other types of colluvium are from Mills (1987), Carter and Ciolkosz (1986), King (1972), Kirby (1967), and Watson and Watson (1970). Debris flow data are from Lawson (1979), Major and Voight (1986), Mills (1984), Rappol (1985), and Bertran *et al.* (1997).

substantial range of fabric patterns is apparent in Fig. 3, involving both clusters and girdles as well as transitional fabrics. These contrasts could indicate: (a) different depositional processes; (b) varying process intensity within deposits of similar origin; or (c) post-depositional modification.

The presence of two identifiable stratigraphic units showing evidence of downslope movement was interpreted by Snyder and Bryant (1992) as reflecting two periods of colluviation. Although we found fabric strength in the red colluvium to be consistently and substantially greater than in the brown colluvium, Snyder (1988, p. 53) observed strong fabrics in both units. Most of our samples from the brown unit are from very shallow depth, and the discrepancy between studies could reflect alteration of fabric patterns in the brown colluvium by seasonal frost. Alternatively, variations in process intensity or environmental conditions at the time of emplacement could be responsible.

Fabrics obtained from solifluction features have typically been measured atop well-developed lobes, locations chosen as being likely to exhibit maximum movement rates (Benedict 1970, fig. 26) and, presumably, strong fabric patterns (Nelson 1985). Potential variability resulting from microenvironmental differences may, therefore, have been highly constrained. Millar (unpublished data) sought to assess potential microenvironmental variations in solifluction macrofabric by implementing a formal spatial sampling design near Eagle Summit in central Alaska. Fabrics were highly variable between samples collected across an area containing abundant morphological evidence of solifluction. In many cases, transitional or girdle-type distributions were observed, demonstrating the inherent variability of fabrics, and that local variations in such factors as soil moisture, soil texture, and geomorphic setting affect fabric strength and shape. Similar local variability should also exist in relict deposits. If the analogy with contemporary southwestern Greenland (van Tatenhove and Olesen 1994) is appropriate, the Salamanca area may have been subject to pronounced geographic

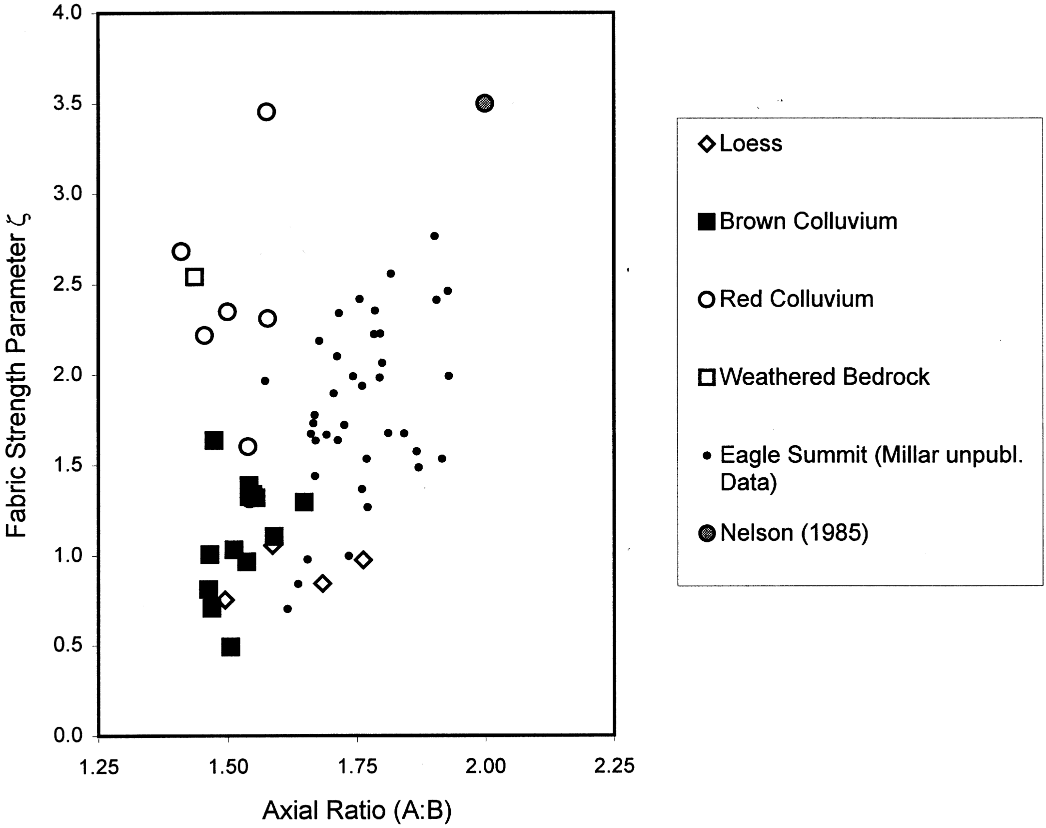

Fig. 5. Plot of A/B clast axial ratio *vs.* fabric strength for Salamanca data, overlain with data from solifluction slopes in a contemporary periglacial environment at Eagle Summit, Alaska (Millar, unpublished data) and eight solifluction lobes at Eagle Summit (Nelson 1985).

contrasts in geocryological conditions. Moreover, the local intensity of moisture-dependent depositional processes is likely to have been highly responsive to environmental gradients induced by changes in the location of the ice-sheet margin (cf. Duynkerke and van den Broeke 1994; van den Broeke *et al.* 1994).

Clast axial ratios

Methodological considerations are an important component of comparative analysis (Mills 1991). Our data are from clasts having moderate axial ratios, unlike those obtained by Nelson (1985), who employed A/B axial ratios of at least 2.0. The significance of particle morphology was demonstrated theoretically long ago (Jeffery 1922), and has been substantiated through empirical work in mud and debris flows (Lindsay 1968; Major 1998), and glacial till (Drake 1974). The angular velocity of rotating particles is greater when a clast's long axis is not parallel with flow vectors. It is also dependent on the degree of clast elongation: more elongate clasts have greater angular velocity. The length of time a clast spends parallel to the flow direction is greater for more elongate clasts, the statistical manifestation of this phenomenon being a clustering of axes subparallel to the downslope direction.

A strong relation between clast axial ratio and fabric strength in contemporary solifluction deposits is shown clearly in Fig. 5. Data from the brown colluvium in the Salamanca area provide further evidence for the influence of axial ratio on fabric strength. Although the small number of samples precludes statistical treatment, the trend of the relation in the Salamanca data fits neatly into the plot of the Eagle Summit data (Fig. 5). Conversely, most samples from the red colluvium plot well away from the primary trend, possibly indicating modification by other processes, such as cryoturbation.

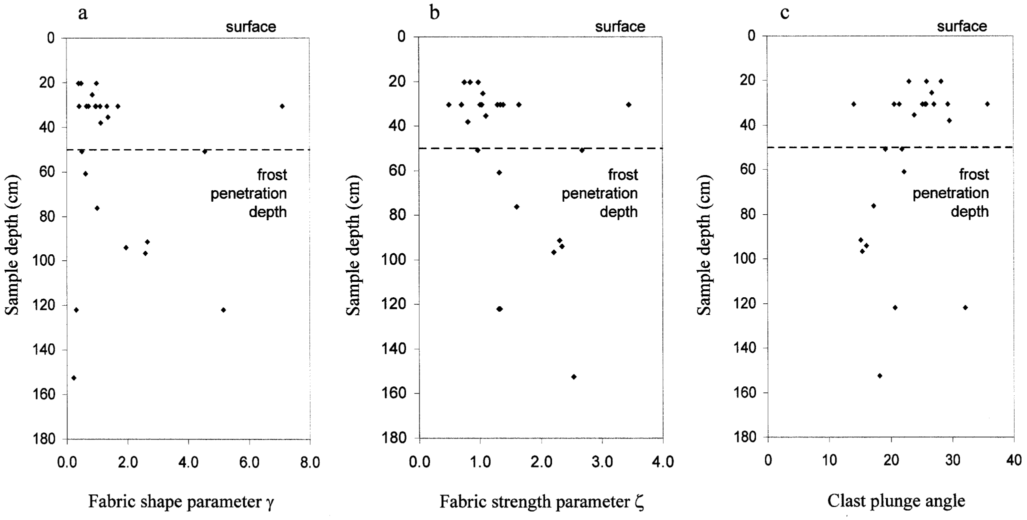

Fig. 6. Plots of sample depth versus (a) fabric shape parameter γ, (b) fabric strength parameter ζ, and (c) average clast plunge. Calculated depth of frost penetration is indicated by dashed horizontal line (see text for further explanation).

Disturbance by frost

Only occasional reference to potential disturbance of fabric by seasonal frost has been made by those examining relict colluvial material (Carter and Ciolkosz 1986). That this issue is not given more attention in such studies is surprising. Evidence for upward displacement of clasts by frost heaving is abundant in the cleared fields of eastern North America. Many stone walls in New England are, in effect, dumping sites for rock debris that surfaces on agricultural land every year through frost heaving (Thorson, in Schneider 1991).

Displacement of stones by frost heaving is usually explained by the frost-push or frost-pull mechanisms (Washburn 1980). Applicability of frost pull in the context of the present study is corroborated by observations that larger and more elongate clasts experience greater heave (Kaplar 1965). This process also rotates elongate clasts so that their long axes become normal to the freezing plane (Johnson *et al.* 1977; Washburn 1980). Mills (1991) observed steeply inclined clasts in relict periglacial colluvium; this may be evidence that frost heaving has affected their orientation.

To assess the extent to which surface fabrics may have been disturbed at the Allegany State Park sites, fabric shape and strength were plotted against sample depth (Fig. 6a and b). Although fabric shape does not appear to be related to depth, fabric strength shows a general transition, from generally weak fabrics in near-surface samples to somewhat greater strength at depth. Weak fabrics near the surface may indicate disturbance after emplacement. Variability at depth may represent local depositional variation at the time of emplacement.

Potential frost penetration at the Salamanca site was calculated using the multilayer form of the Stefan solution for frost/thaw penetration depth with phase change (e.g. Jumikis 1977). Soil moisture content and textural characteristics were estimated from Snyder's (1988) description of soil properties, and used to obtain values of thermal conductivity from nomograms (Andersland and Anderson 1978, p. 115–117) of Kersten's (1949) data. Results, using seasonally averaged temperature data from the Allegany State Park climate observation station for the period 1964–1993, indicate that frost heave in treeless areas may regularly affect soils to a depth of more than 0.5 m. The depth of frost penetration may, however, have been substantially greater at the close of the Pleistocene, during cold phases of the Holocene, and immediately after land clearance (Bonan 1999).

Figure 6c indicates a negative relation between average clast inclination and sample depth. Clasts in samples from shallow depths have generally steeper inclinations, indicating that frost heaving has reoriented near-surface stones. Fabric shapes in the loess are transitional and, collectively, have the weakest fabric of any of the units (Fig. 3). Clasts within the loess were probably derived from the underlying brown colluvium through frost heaving.

This interpretation is supported by the observation that two of the samples from loess, despite having the largest clast axial ratios in the entire data set, have very weak or uniform fabrics (Fig. 5 and Table 2). It appears highly likely that the orientation of clasts in the uppermost colluvial units was disturbed by seasonal frost. Disruption of colluvial fabrics by frost heaving is possible throughout the northeastern United States and, indeed, in the majority of locations considered to have experienced periglacial conditions during the Pleistocene.

Conclusions

Results from detailed analysis of clast fabric are consistent with Snyder and Bryant's (1992) conclusion that the red and brown colluvial units in Allegany State Park were emplaced by periglacial processes. Although generally weaker than those in a large number of samples obtained near Eagle Summit, Alaska, fabrics from the brown colluvium fall within the lower range of the eigenspace occupied by the Alaskan data. The relation between clast axial ratio and fabric strength in the brown colluvium is consistent with the Alaskan data. Strength is greater in the red colluvium, but fabrics from this unit plot outside the fabric-strength/axial-ratio envelope defined by the Alaskan data. Although not conclusive, this discrepancy may provide support for Snyder and Bryant's (1992) interpretation that the red colluvium was subjected to a secondary influence, possibly cryoturbation.

Fabric analysis is one diagnostic tool among several (Harris 1981), rather than a sole criterion for inferring depositional process. This study calls into question some basic assumptions that have been used to interpret colluvium as relict solifluction deposits. Assuming that solifluction fabrics must show evidence of strong clustering oversimplifies a complex environment. For strongly clustered fabrics to develop, local environmental (e.g. microclimate and soil moisture) and sedimentological (e.g. soil texture and mineralogy) factors conducive to solifluction must coincide in time and space. Sampling programs should, therefore, encompass as broad a range of local terrain and exposure as possible. In relict deposits it is crucial that stratigraphic relations in the local area be well understood to enable assessment of the range of possible microenvironments sampled.

Sampling design is a critical but underrepresented aspect of fabric analysis in colluvial deposits. The strong relation between clast morphology and fabric strength indicates that sampling within a strictly prescribed range of A/B axial ratios is essential if meaningful comparative work is to be performed. We suggest a modest, centrally located range as most appropriate.

Seasonal frost penetration can disturb fabrics in near-surface soil. Typically, the most accessible areas for fabric sampling are those where forest cover has been removed and disturbance by frost has been greatest. Sampling programs in climatic environments susceptible to seasonal frost require knowledge of the potential depth of frost penetration to avoid collection from disturbed layers.

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