Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **26**, 523–529 (2001)

SAMPLING-SURFACE ORIENTATION AND CLAST MACROFABRIC IN PERIGLACIAL COLLUVIUM

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Received 16 March 2000; Revised 6 September 2000; Accepted 17 October 2000

ABSTRACT

To isolate the influence of sampling-surface orientation on the macrofabric of periglacial colluvial deposits, clast orientation measurements were obtained from seven paired horizontal and vertical exposures in turf-banked solifluction lobes on Niwot Ridge, Colorado Front Range. Most samples form moderately strong, upslope-plunging clusters aligned with the local slope orientation. Fabrics obtained from vertical faces were stronger than those from horizontal exposures in six of the pairs. Near-horizontal sampling surfaces yield less biased results than vertical exposures, owing to operator perceptions, procedural difficulties, and the relative thinness of the layer affected by colluvial processes. Sampling procedures must be standardized before comparative studies of colluvium can yield reliable results. Copyright © 2001 John Wiley & Sons, Ltd.

KEY WORDS: clast fabric; periglacial colluvium; sampling; solifluction; spherical statistics

INTRODUCTION

The three-dimensional orientation of clasts embedded in a matrix of finer material has been used widely to infer details about depositional environments and fluvial, glacial and mass-movement processes. In the context of colluvial deposits, results from several investigations (e.g. Nelson, 1985; Francou, 1990; Nieuwenhuijzen and Van Steijn, 1990; Mills, 1991; Bertran *et al.*, 1997) indicate that clast fabric constitutes a useful part of procedures for identifying mechanisms of movement and emplacement.

Despite an early plea for standardization of measurement techniques in all phases of till fabric analysis (Andrews, 1971), review of the literature indicates that scant attention has been given to this topic during the intervening years. Divergences in the sampling strategies employed by various workers may be a source of serious problems for comparative studies, including those involving colluvium, a point emphasized in the survey by Mills (1991).

Field procedures in clast fabric analysis involve sampling decisions made at several levels of spatial resolution. For convenience, these can be divided into three categories along a continuum of geographical scale: (1) *microscale* decisions, involving the size, geometry and composition of individual rock particles from which orientation information is obtained; (2) *mesoscale* decisions, concerned with such site characteristics as the topographic position and orientation of sampling surfaces; and (3) *macroscale* considerations, involving the location and relative arrangement in geographic space of landform assemblages and sampling sites. The work reported here is concerned with the second category.

In the course of collecting data for an extensive study of fabrics on slopes affected by periglacial solifluction near Eagle Summit, Alaska (S. W. S. Millar, unpublished data), evidence arose indicating that the orientation of the surface in sampling pits can affect fabric strength and shape. This influence appeared to extend even to the orientation of sample principal axes. In this note we report results from a field experiment

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Contract/grant sponsor: U.S. National Science Foundation; contract/grant number: SBR-9305029

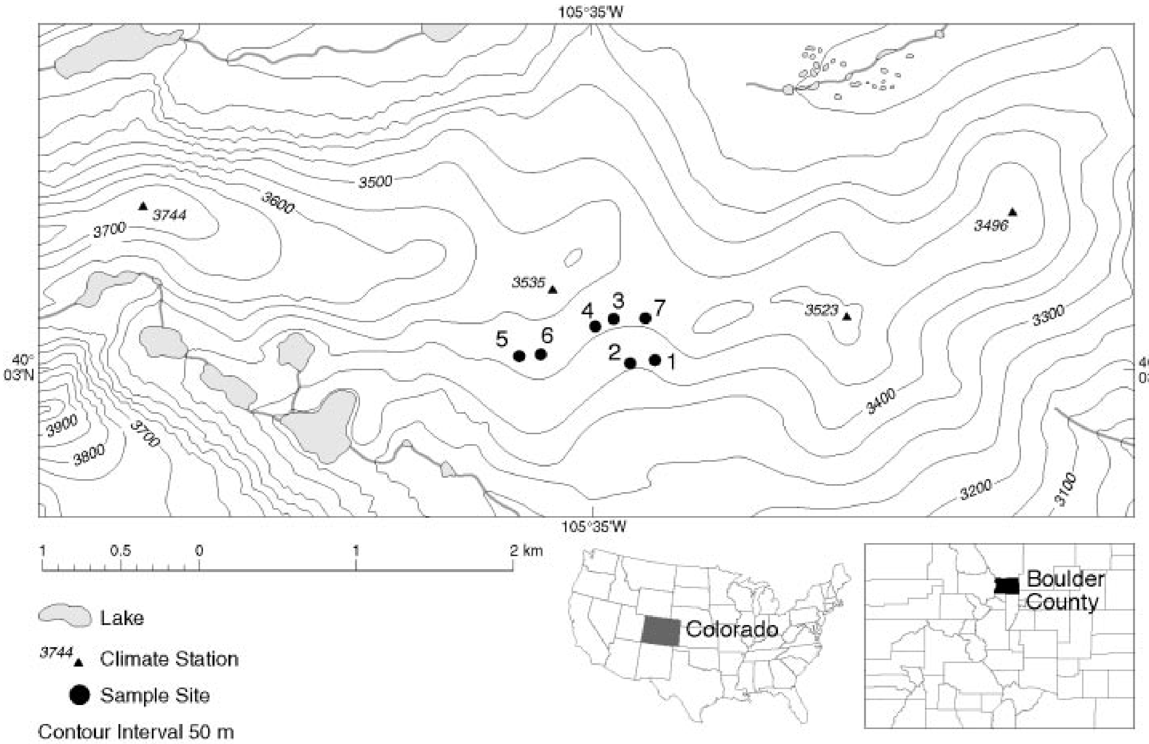

Figure 1. Map of Niwot Ridge area, showing locations of sampling sites

designed to assess how the orientation of sampling surfaces can affect clast macrofabrics in colluvial materials.

STUDY AREA AND SAMPLING METHODS

Data were collected above treeline on Niwot Ridge (40 ° 03′ N, 105 ° 35′ W; 3400–3550 m a.s.l.), Colorado Front Range (Figure 1), in the general vicinity of Benedict's (1970) classic investigation of mass-movement processes. Paired samples of clast orientation were obtained from seven shallow pits excavated in well-formed turf-banked solifluction lobes. Sites were cleared of vegetation by rolling back the turf mat and exposing the underlying soil matrix. The uppermost 20 cm of soil was removed to eliminate potential contamination from disturbance by foot traffic. Although penetration of frost into near-surface sediments may have affected clast orientation (Fahey, 1975; Warburton, 1990; S. W. S. Millar and F. E. Nelson, unpublished data), the pairing of samples from equivalent depths controlled for this factor.

In each of the seven pits, the plunge and plunge azimuth of 50 elongate clasts were obtained, following procedures outlined by Andrews (1971). Clasts were measured from the subhorizontal floor of the $1 \times 1 \times 0{\cdot}6$ m pits at depths between 20 and 60 cm as excavation proceeded. The work involved careful unearthing and removal of each clast to identify the true A-axis. A non-metallic rod was inserted to replicate A-axis plunge and plunge azimuth, which were then measured with a Brunton compass corrected for local magnetic declination. Only clasts with A:B axial ratios greater than 1·5 were measured. For comparative purposes, a second set of 50 observations was obtained from the vertical, upslope face of the pit over the same depth increment, following collection of the horizontal sample. To obtain the sample quota of 50 observations, the vertical faces of the pits were trimmed back by as much as 0·5 m. This sampling design yielded seven paired samples of fabric data, each obtained from a 0·4 to 0·6 m^3 volume of sediment, and potentially appropriate for application of two-sample comparative statistical procedures.

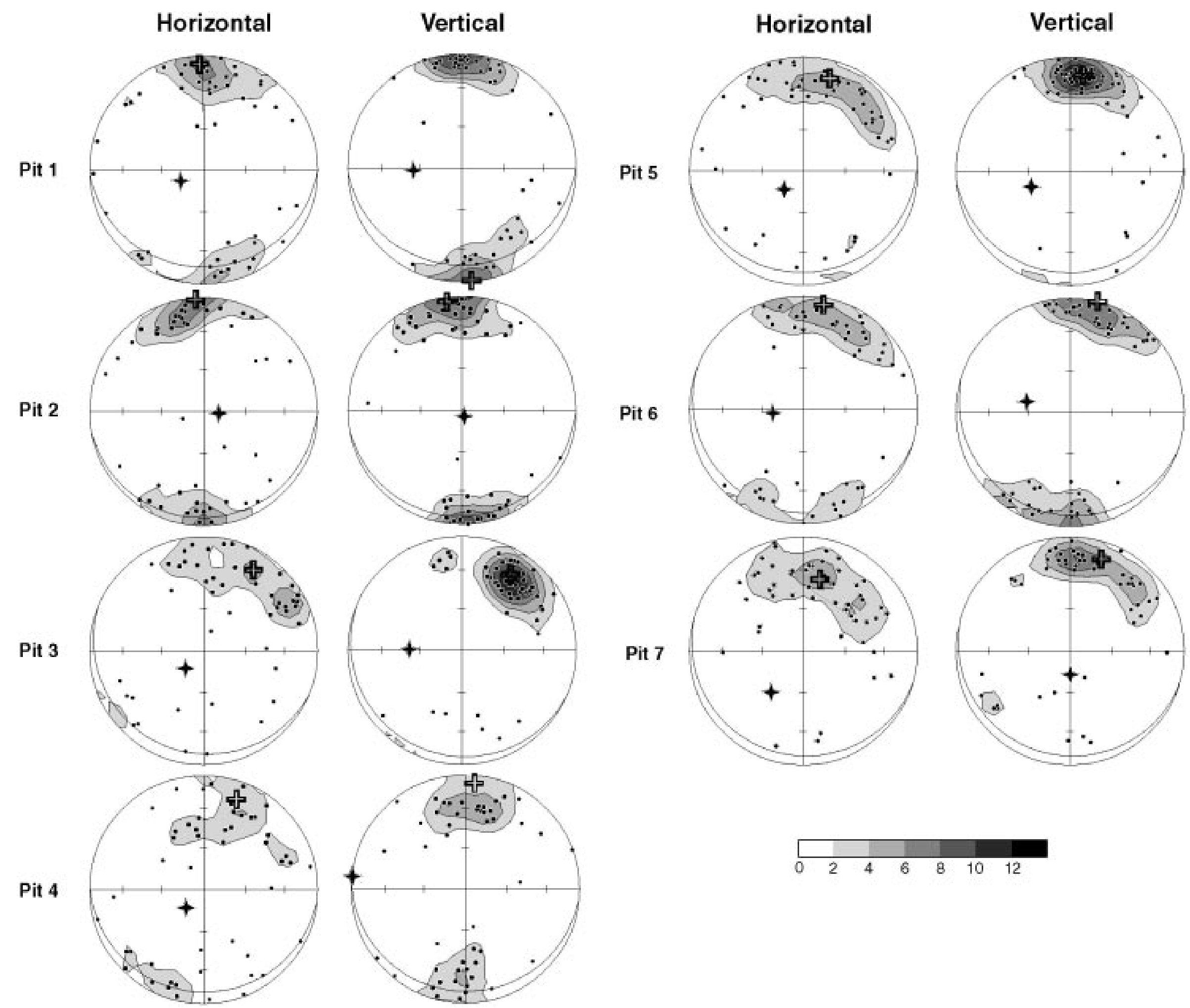

Figure 2. Fabric data from horizontal and vertical sampling faces, plotted on Schmidt nets (Lambert equal-area projection). Great circles represent plane of local slope at each sampling location. Largest and smallest eigenvectors are shown by open and solid crosses, respectively. Contouring was implemented using Starkey's (1977) point-counting method; each counting circle occupied 2 per cent of projective net (Stesky, 1998). Contours represent 2, 4, 6, 8, 10 and 12 points per circle. Shading density is standardized between nets

STATISTICAL ANALYSIS

The seven paired data sets were plotted on Schmidt nets and contoured using Starkey's (1977) point-counting method (Figure 2). A dominant mode coincides approximately with the orientation of the local slope in each case. Visual inspection indicates that dispersion is substantially greater in samples obtained from horizontal sampling surfaces. This impression was confirmed by descriptive measures of sample orientation and dispersion (Table I), generated using standard eigenvalue techniques for axial data (Mardia, 1972, Ch. 8; Fisher *et al.*, 1987, Ch. 3). Normalized eigenvalues $\overline{\tau}_i$ ($i = 1, 2, 3$; $\overline{\tau}_3 \geq \overline{\tau}_2 \geq \overline{\tau}_1$) computed from a 3×3 orientation matrix **T** (Fisher *et al.*, 1987 p. 33) for each sample indicate appreciable differences in fabric strength between paired samples. Moderately strong clusters predominate, although several are embedded in a more dispersed girdle-like pattern corresponding to clasts orientated transverse to the slope. Samples from vertical exposures are stronger in all cases except Site 7, where the horizontal face yielded a slightly stronger

Table I. Sample characteristics

Sample	$\bar{\tau}_1$	$\bar{\tau}_2$	$\bar{\tau}_3$	$\mathbf{t}_3$[a]	γ[b]	ζ[c]	Γ[d]	$\hat{\sigma}$[e]	P_n[f]	N_r[g]
1h	0·088	0·241	0·671	358, 8	1·018	2·030	0·527	0·125	12·63	–
1v	0·047	0·182	0·771	175, 1	1·063	2·804	0·660	0·080	15·62	
2h	0·112	0·173	0·715	356, 2	3·245	1·853	0·583	0·095	2·44	34·18
2v	0·080	0·113	0·807	352, 5	5·691	2·311	0·692	0·069	1·42	
3h	0·145	0·223	0·632	32, 18	2·395	1·476	0·470	0·139	3·01	0·36
3v	0·068	0·151	0·781	33, 22	2·052	2·440	0·690	0·069	5·40	
4h	0·191	0·231	0·578	20, 17	4·877	1·105	0·412	0·166	0·61	3·5
4v	0·136	0·205	0·659	5, 8	2·816	1·580	0·494	0·127	2·75	
5h	0·083	0·274	0·643	16, 17	0·711	2·051	0·492	0·149	17·80	–
5v	0·037	0·158	0·805	8, 16	1·115	3·088	0·718	0·064	13·68	
6h	0·086	0·206	0·708	11, 7	1·400	2·114	0·544	0·114	11·43	–
6v	0·060	0·109	0·831	14, 0	3·445	2·624	0·705	0·069	5·46	
7h	0·104	0·251	0·645	13, 36	1·077	1·825	0·491	0·141	10·71	–
7v	0·125	0·199	0·675	19, 16	2·635	1·684	0·534	0·112	2·97	

All samples consist of 50 replications of plunge and plunge azimuth. Mardia's (1972, p. 276) test indicates that the null hypothesis of uniformity should be rejected for all samples (0·05 level).

[a] Values for azimuth, plunge of principal eigenvector $\mathbf{t}_3$

[b] Shape parameter: $\gamma = \ln(\bar{\tau}_3/\bar{\tau}_2)/\ln(\bar{\tau}_2/\bar{\tau}_1)$

[c] Strength parameter: $= \ln(\bar{\tau}_3/\bar{\tau}_1)$

[d] Fourth cosine moment

[e] Spherical standard error

[f] Test statistic for rotational symmetry (critical value at 0·05 level is 5·99)

[g] Test statistic for two-sample test for common principal axis; critical value is compared with χ^2_2 (see Fisher *et al.*, 1987, p. 165)

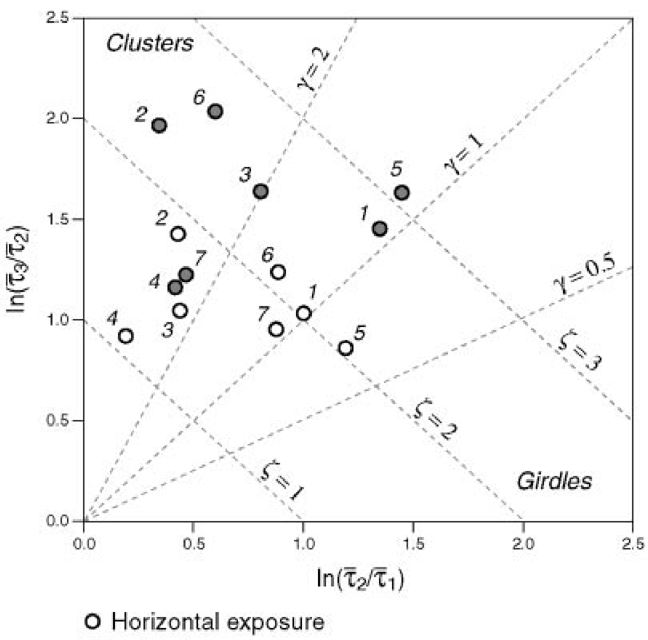

Figure 3. Log-ratio plot of Niwot fabric data

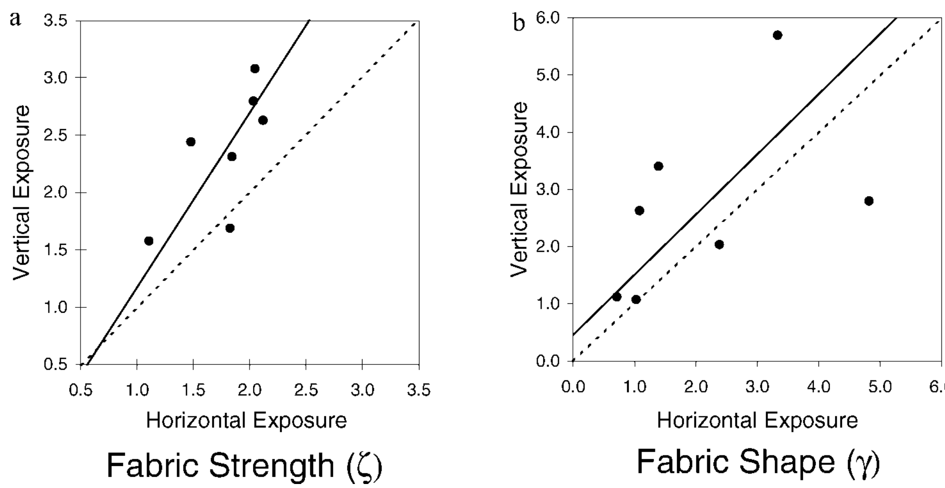

Figure 4. Plot showing (a) fabric strength (ζ) and (b) fabric shape (γ) in samples obtained from horizontal and vertical exposures. Low values of shape parameter describe girdle distributions; higher values indicate clusters. Dashed lines indicate 1:1 relation; solid lines represent reduced major axes (RMA)

fabric. The shape of the fabric from the vertical face at Site 7 was, however, more clustered than that obtained from the horizontal exposure.

Parameters describing the shape (γ) and strength (ζ) of the samples were used to create log-ratio plots (Woodcock, 1977), which can facilitate comparison of fabrics (e.g. Nelson, 1985). Collectively, these measures provide further confirmation that substantial differences exist between samples collected from horizontal and vertical faces (Figure 3).

To investigate these differences further, reduced major axis (RMA) analysis (e.g. Till, 1974, p. 99) was used to construct bivariate strength and shape relations for fabrics from the horizontal and vertical faces (Figure 4). Based on the Pearson product-moment correlation coefficient (r_s), the reduced major axis partitions deviation from the best-fit line equally between variables. Differences in strength between pairs are well developed and systematic ($r_s = 0{\cdot}708$). Fabrics from vertical exposures are substantially stronger than those from their horizontal counterparts (Figure 4a); although a consistent relation between the two sets of samples is apparent, the RMA departs markedly from 1:1 correspondence, with more pronounced differences apparent as strength increases. The slope of the reduced major axis for fabric shape is closer to unity, but substantiates that samples from vertical exposures are generally more clustered. A wider scatter of data points ($r_s = 0{\cdot}508$) occurs between samples than is the case for fabric strength.

To obtain a formal assessment of the correspondence in orientation between sample pairs and to indicate if the pairs can be considered to have been drawn from similar populations, two-sample tests for a common principal axis (Fisher *et al.*, 1987 p. 225) were undertaken. Of the seven paired samples, three (sample pairs 2, 3 and 4) meet the test's requirements of rotational symmetry and roughly comparable dispersion. A rule of thumb for evaluating whether dispersions are comparable is that the quantity $n^{1/2}\hat{\sigma}$ for one sample should not be more than twice the value for the other (N.I. Fisher, personal communication). Results from these tests indicate that in two cases (sample pairs 3 and 4) the pairs share a common principal axis. Applied to pair 2, however, the two-sample procedure indicates that the principal axes of the horizontal and vertical samples are significantly different (Table I).

DISCUSSION

Observations made during the course of the field sampling programme highlight three closely related factors contributing to the greater fabric strengths obtained from vertical exposures: (a) as noted by Andrews (1971,

p. 11), clasts projecting out from the fine matrix (i.e. those with long axes orientated subparallel to the direction faced by the slope) are most obvious to the observer; (b) clasts orientated subparallel to the slope are easiest to measure from vertical exposures using standard compass-and-rod field procedures; and (c) clasts with long axes parallel to the face of the exposure have a tendency to fall from the vertical wall during preparation of the exposure.

Accurate measurement of clast orientation requires removal of a stone from the surrounding matrix and insertion of a non-metallic rod into the cavity to replicate the stone's position. A cavity is much more likely to remain open and stable if the long axis of the stone is orientated with the slope. Conversely, a clast orientated subparallel with a vertical sampling surface is much more difficult to see and remove without caving. Consequently, such clasts are less likely to be sampled.

Observations from the floor of a pit may constitute less biased samples because ease of access to clasts orientated parallel and transverse to the slope is approximately equal. Clasts with a primary axis projecting directly out of a horizontal exposure are likely to have been rotated by frost-heaving processes (Washburn, 1980, p. 88). The latter are most prevalent in near-surface layers, which are to be avoided assiduously in the context of most fabric studies (e.g. Wright, 1957; Millar and Nelson, unpublished data).

Benedict (1970) found that the combined influence of solifluction and frost creep extended to a depth of about 50 cm in lobes and terraces on Niwot Ridge, while Fahey (1974) observed vertical displacement by frost heave of up to 30 cm in the same general area. Because our samples were obtained over the depth increment 20–60 cm they probably include clasts that were rotated by frost heave, as well as some unaffected by contemporary mass movement. The data sets therefore represent composite samples of clasts affected by orientating mechanisms that vary in nature and intensity over the vertical extent of the sections from which they were collected.

The possibility exists that microscale variations in process intensity could be a factor in differences between sample pairs. Although little is known about the variability of movement rates at depth within very small volumes of colluvium, Benedict's (1970) investigations show that the range of movement rates in vertical profiles through turf- and stone-banked lobes and terraces on Niwot Ridge is larger than those measured laterally across the surfaces of these features. Analyses by Caine (1982) demonstrated that the lateral variability of movement rates is insignificant at the scale of the individual pits used in the present study. A study of macrofabrics in glacial till by Young (1969) found considerably more variability in the vertical dimension than laterally over small (<1 m) distances. These observations indicate that sampling-face orientation is more likely than lateral variations in movement rates to be the primary factor responsible for pairwise differences in fabric strength and orientation. This interpretation could be tested further by concentrating sampling efforts on relatively thin layers with greater extent parallel to the ground surface.

CONCLUSIONS

Sampling surfaces used to obtain data for fabric analysis commonly present themselves as specific, often short-lived opportunities, such as situations involving road cuts or the walls of borrow pits. Such practical constraints notwithstanding, pronounced and consistent differences in the strength of paired fabric samples in this study indicate that the orientation of the sampling face can exercise a significant influence over both the fundamental characteristics and the details of fabric signature. It follows that the effectiveness of clast fabric as a diagnostic tool is dependent on such mesoscale sampling considerations, and that the orientation of sampling exposures should be reported in subsequent investigations. Similar concerns have been advanced recently in the context of microscale sampling decisions (Kjær and Krüger, 1998; Major, 1998).

Mills (1991), echoing earlier pleas by Andrews and King (1968), Hill (1968) and Andrews (1971), pointed to the need for standardization of sampling procedures before firm conclusions can be reached about the effectiveness of clast fabric analysis for discriminating between sedimentary processes and depositional environments. Nonetheless, sampling procedures remain an under-investigated topic in studies of clast macrofabric. Given this situation, indictments of the entire enterprise (Bennett *et al.*, 1999) may be premature.

ACKNOWLEDGEMENTS

This work was supported by the US National Science Foundation (grant no. SBR-9305029). We thank D. M. Mitchell (Syracuse University) for assistance in the field and N. I. Fisher (CSIRO, Sydney) for timely and generous advice on statistical procedures. Critical comments from J. C. F. Tedrow, G.M. Ashley, D.A. Robinson (all of Rutgers University) and an anonymous reviewer led to numerous improvements in the manuscript. Responsibility for any remaining errors or misconceptions rests entirely with the authors.

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