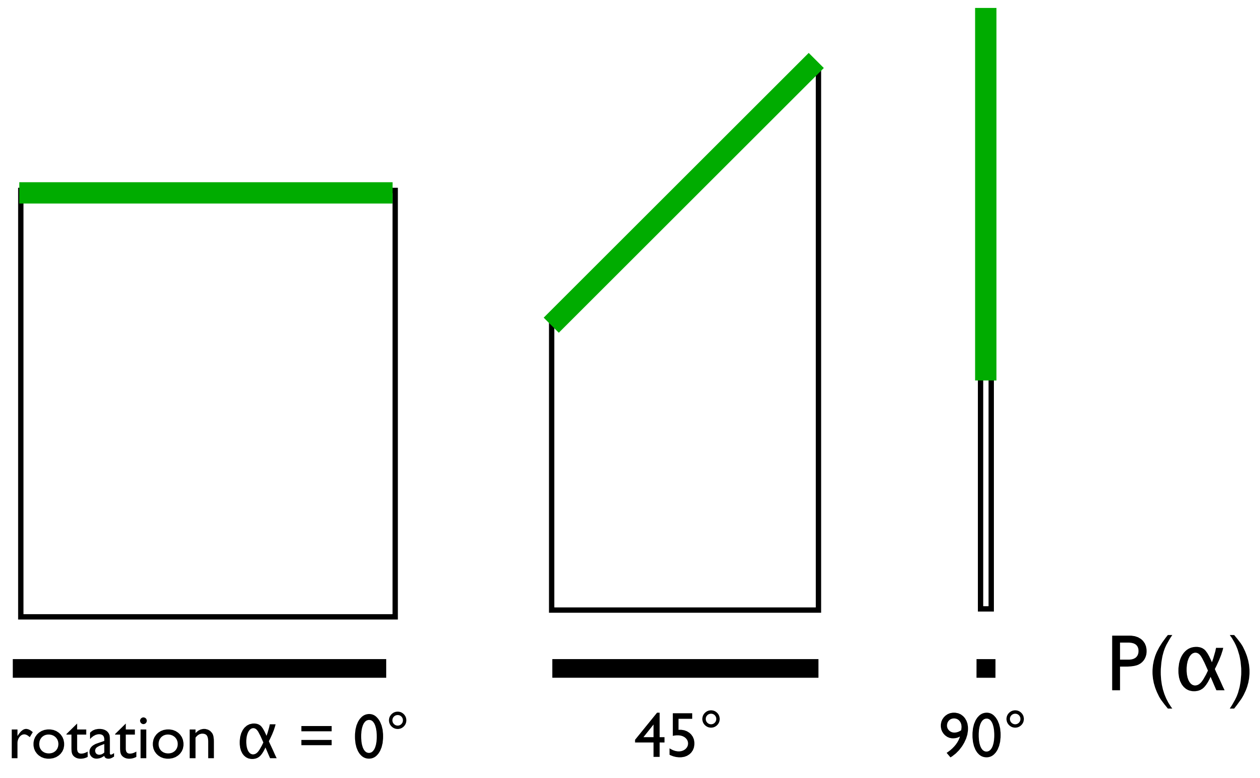



**Figure 15.1**
Length of projection of a single line segment.
P(α) depends on the length and orientation of the line segment.

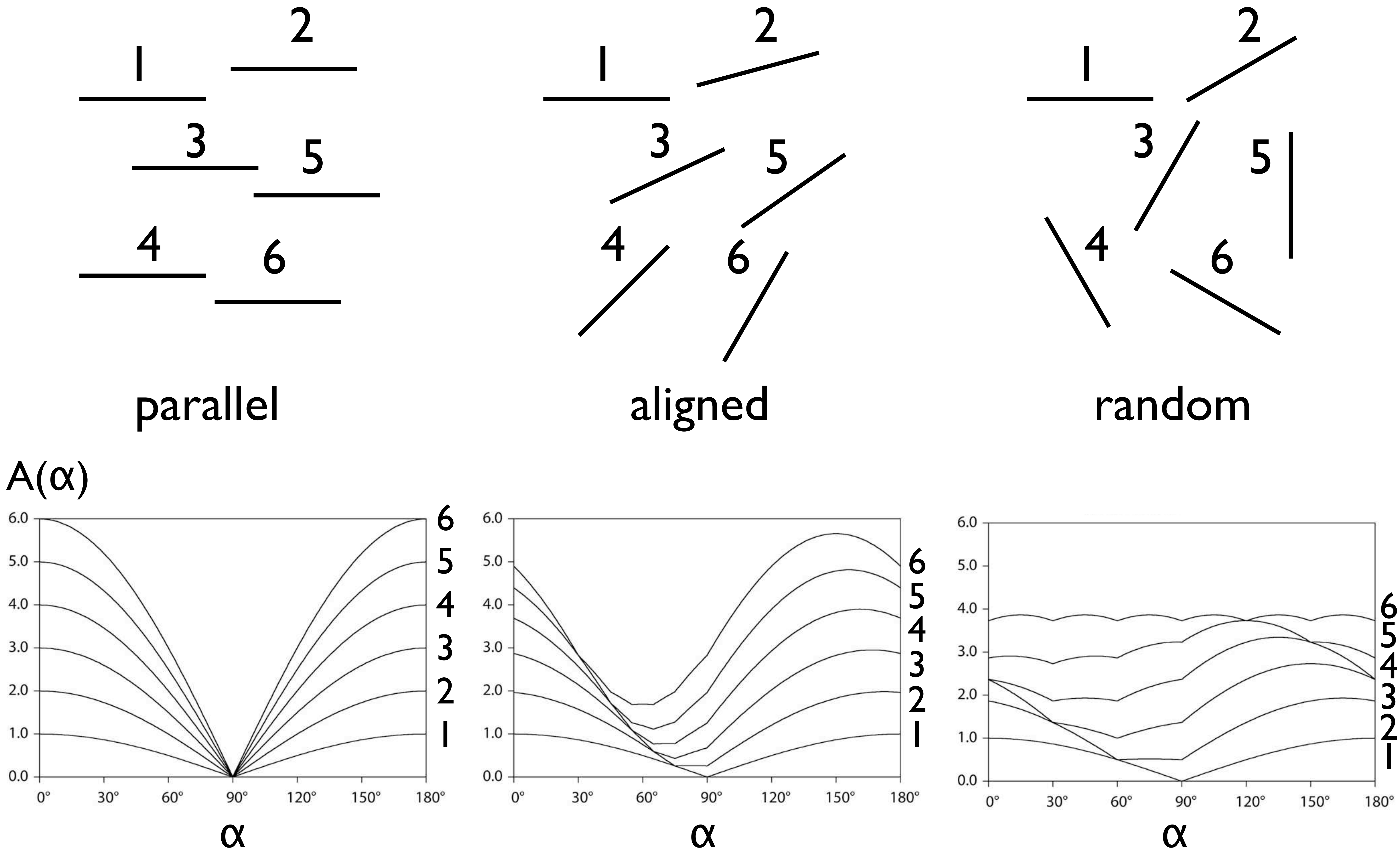
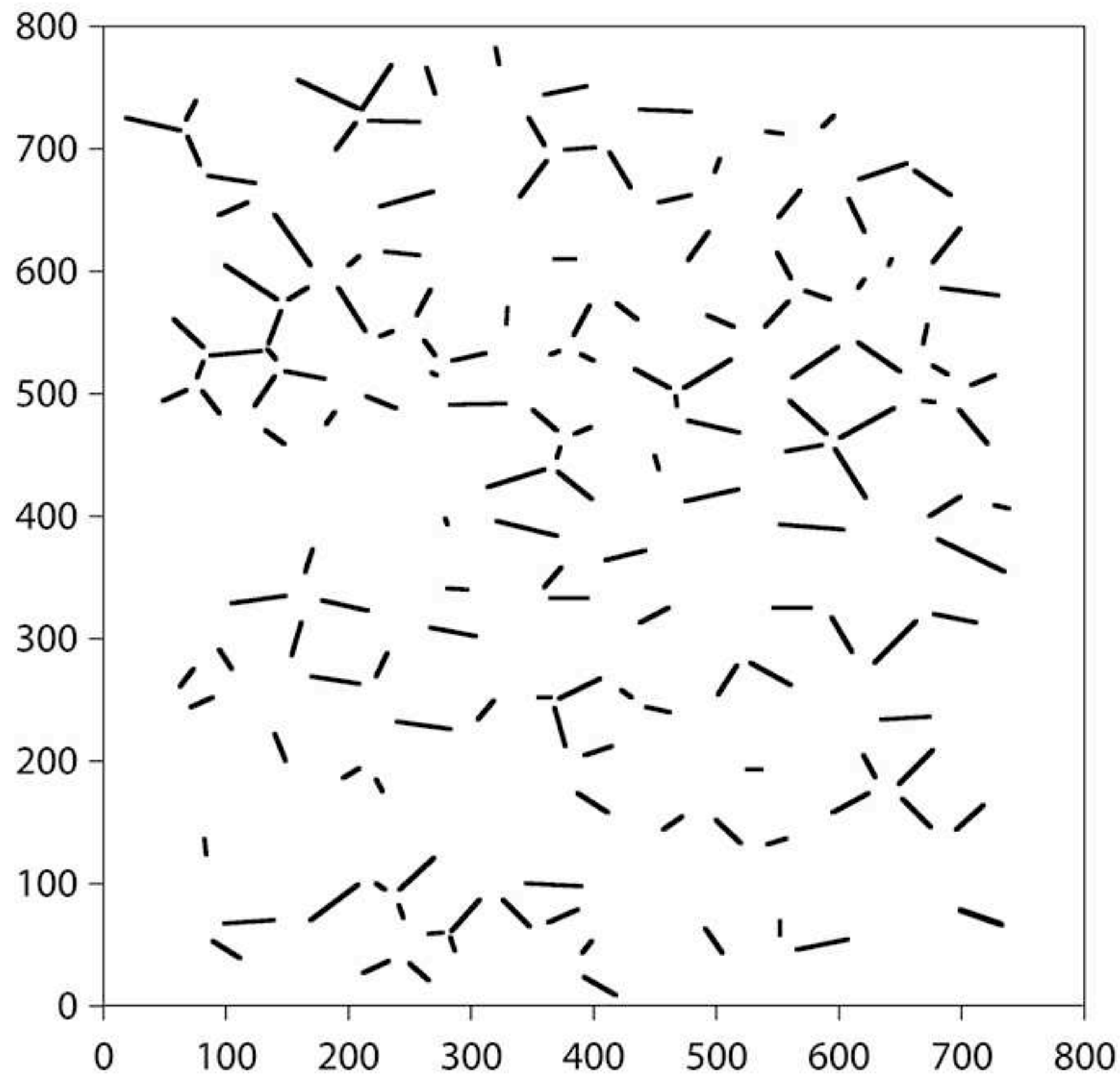



**Figure 15.2**
Projection curves, A(α), of sets of lines.
The projection curves of the individual lines (labeled 1 to 6) are shown as cumulative plots.
(a) Parallel lines: orientation distribution function (ODF) = delta function: $h(\alpha_i) = \infty$ if $\alpha_i = 0°$; fabric as a whole has same anisotropy as individual lines;
(b) lines with preferred orientation: ODF = normal distribution: $h(\alpha_i) = 30° \pm 10°$; fabric as a whole is less anisotropic than individual lines;
(c) randomly oriented lines: ODF = uniform distribution; fabric as a whole is isotropic.

```
hand digi of bitmap ps.tif
 474
  19.0000   725.0000
  63.0000   715.0000
9999.0000  9999.0000
  68.0000   724.0000
  76.0000   739.0000
9999.0000  9999.0000
  69.0000   710.0000

   .... etc.

9999.0000  9999.0000
 699.0000    79.0000
 732.0000    67.0000
9999.0000  9999.0000
 266.0000    59.0000
 277.0000    60.0000
9999.0000  9999.0000
 283.0000    56.0000
 287.0000    45.0000
9999.0000  9999.0000
```




**Software Box 15.1**
Input file ps.dig.scm with x-y coordinates of line segments; plot of file.

```
   ------------------------------------------------------------
   ***  surfor  ***                               2010-11-08, rh
   analysis of bulk surface fabric
   (open or closed outlines)
   ------------------------------------------------------------
   input file:
      line 1:           bti          title (must have)
      line 2:           n            total number of points
      line 3 ff.:       x,y          floating x-y coordinates
      |                 ...          ...etc.
      | (optional)      Xend,Yend    end coordinates
   ------------------------------------------------------------
   number of points and particles is unlimited
   ------------------------------------------------------------
   name of input file >
1 ps.dig.scm
   end coordinates in input (0.000, 9999, ... one number) >
2 9999
   do you want printout (0), file (1), both (2) ? >
3 1
   increment of rotation angle (minimum = 1 deg.) >
4 10
5  name of output file ? [ps.dig.s10] (return=default) >
6  name of file with A(alfa) curve ? [ps.dig.i10] >
7  name of file with surface ODF ? [ps.dig.r10] >
8  name of file with characteristic shape? [ps.dig.c10] >
```

**Software Box 15.2**
Dialog with program SURFOR; answers are numbered and highlighted, see text for explanation.

| 10° | 5° | 1° | file type |
|---|---|---|---|
| file.s10 | file.s05 | file.s01 | screen output |
| file.c10 | file.c05 | file.c05 | characteristic shape |
| file.i10 | file.i05 | file.i05 | A(α) curve |
| file.r10 | file.r05 | file.r05 | ODF of line segments |

**Table 15.1**
Default name extensions used for result files created by the SURFOR program.
For angular resolutions of 10°, 5° and 1°.

```
surfor analysis of ps.dig.scm
```

1

```
A(alfa)min =          48.049            A(alfa)max =        75.461
Alfamin =             90.0              Alfamax =          180.0
Bulk b/a =                   0.63674
Angular difference =       90.0
(diff < 90 deg = dextral monoclinic)

Preferred orientation (of LA1) alfap1 =     0.
Preferred orientation (of LA2) alfap2 =     0.
```

```
A(alfa)min =          47.972            A(alfa)max =        75.481
Alfamin =             93.0              Alfamax =            1.0
Bulk b/a =                   0.63555
Angular difference =       88.0
(diff < 90 deg = dextral monoclinic)

Preferred orientation (of LA1) alfap1 =   179.
Preferred orientation (of LA2) alfap2 =    -3.
```

2

```
number of projected line segments:   158
                                      150 where delta x > 0
                                        8 where delta x < 0

total length of projected line segments, a(alpha):
 angle       total          mean      variance      st.dev.      skewness
    10   3369.37695     21.32517    181.52255     13.47303     19.84693
    20   3243.18896     20.52651    187.75998     13.70255     20.32314
    30   3060.17358     19.36819    188.57220     13.73216     22.56540
    40   2851.98218     18.05052    179.71555     13.40580     26.33520
    50   2674.60596     16.92789    155.02504     12.45090     33.72395
    60   2489.10498     15.75383    131.44009     11.46473     36.71122
    70   2341.69922     14.82088    107.45545     10.36607     37.33000
    80   2229.43018     14.11032     91.31422      9.55585     32.75957
    90   2168.07959     13.72202     85.66262      9.25541     27.05326
   100   2186.56372     13.83901     88.18482      9.39068     27.74048
   110   2303.29956     14.57785     94.42200      9.71710     35.46484
   120   2442.61035     15.45956    113.43501     10.65059     33.61173
   130   2621.44507     16.59142    135.38664     11.63558     29.00960
   140   2819.18042     17.84291    156.22311     12.49892     23.43901
   150   3003.85620     19.01175    175.08154     13.23184     17.07845
   160   3200.54297     20.25660    178.59958     13.36411     16.01733
   170   3346.21240     21.17856    177.01588     13.30473     17.35884
   180   3404.96533     21.55041    177.59029     13.32630     18.83508
```

3

```
histogram: total length of projection A(alpha) versus angle of rotation
            0                      length units                    3405
            ------------------------------------------------------------
        10  :::::::::::::::::::::::::::::::::::::**********************
        20  ::::::::::::::::::::::::::::::::::::::*******************
        30  ::::::::::::::::::::::::::::::::::::::***************
        40  :::::::::::::::::::::::::::::::::::::*************
        50  ::::::::::::::::::::::::::::::::::*************
        60  :::::::::::::::::::::::::::::::************
        70  ::::::::::::::::::::::::::::*************
        80  ::::::::::::::::::::::::::*************
        90  :::::::::::::::::::::::::*************
       100  ::::::::::::::::::::::::::************
       110  :::::::::::::::::::::::::::*************
       120  :::::::::::::::::::::::::::::**************
       130  ::::::::::::::::::::::::::::::::**************
       140  ::::::::::::::::::::::::::::::::::***************
       150  ::::::::::::::::::::::::::::::::::::****************
       160  :::::::::::::::::::::::::::::::::::::*******************
       170  :::::::::::::::::::::::::::::::::::::*********************
       180  :::::::::::::::::::::::::::::::::::::***********************
```

**Software Box 15.3**

SURFOR output file ps.dig.s10:

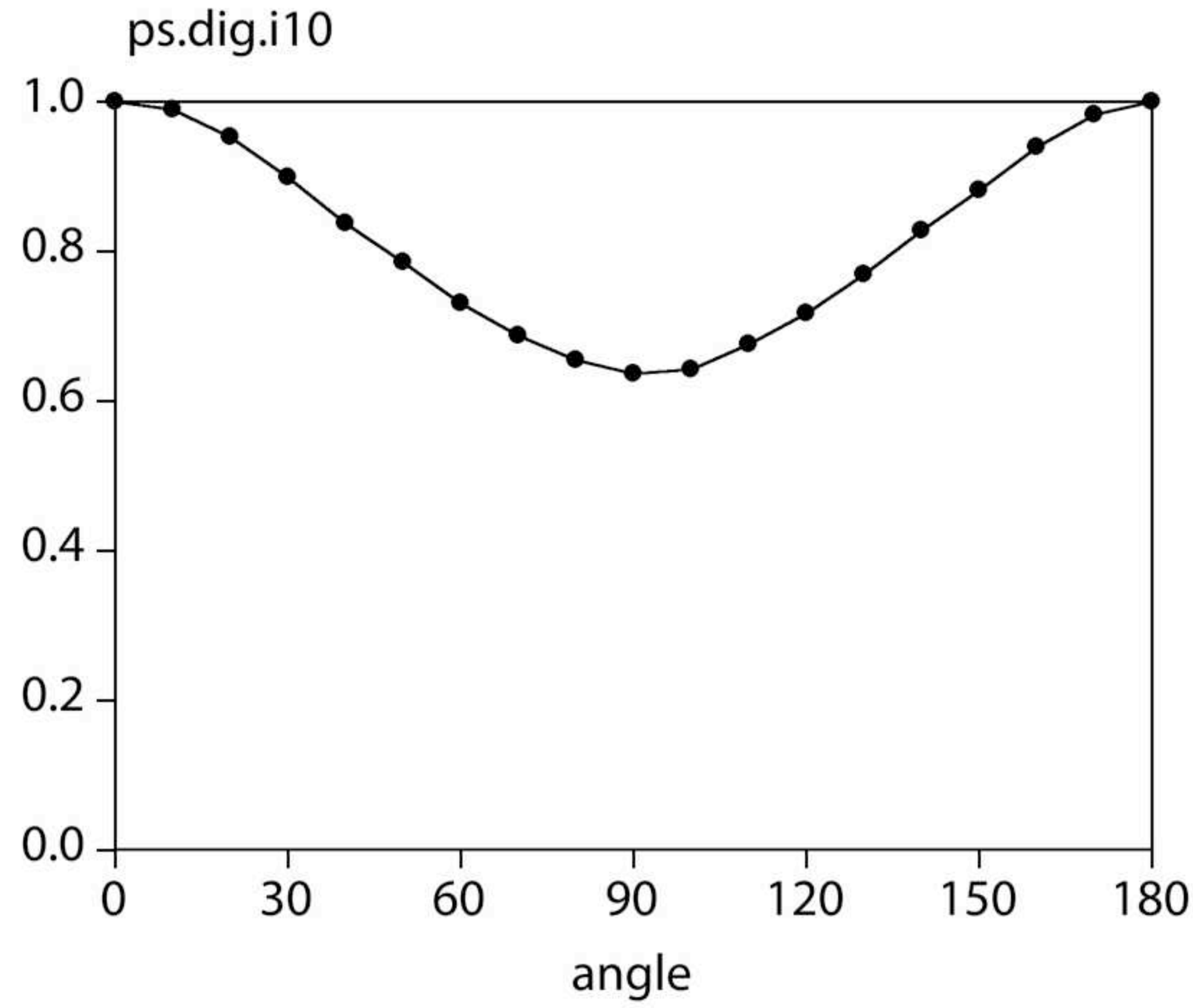
(1) calculation of $A(\alpha)_{max}$, $A(\alpha)_{min}$, $\alpha_{max}$ and $\alpha_{min}$ for 10° increments; angular difference is between $\alpha_{max}$ and $\alpha_{min}$; inset: output file ps.dig.s10: calculation of $A(\alpha)_{max}$, $A(\alpha)_{min}$, $\alpha_{max}$ and $\alpha_{min}$ for 1° increments;

(2) length of projection, $A(\alpha)$, list of values;

(3) total length of projection and standard deviation, shown as histogram: (stars) = total length; (colons) = standard deviation as fraction of total length.

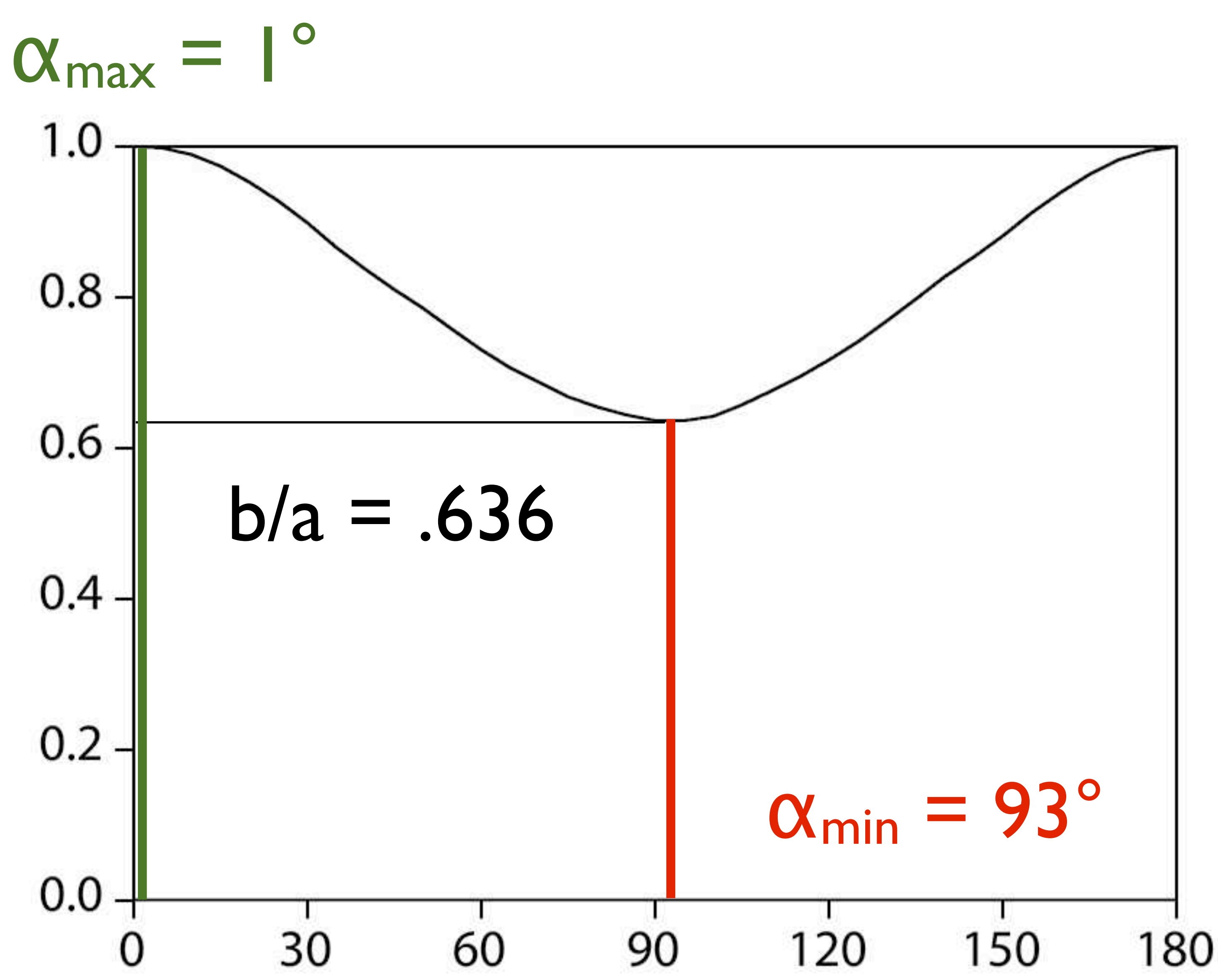
**1**

| angle | relative_length_of_projection |
|---|---|
| 0 | 1.00000 |
| 10 | 0.98955 |
| 20 | 0.95249 |
| 30 | 0.89874 |
| 40 | 0.83760 |
| 50 | 0.78550 |
| 60 | 0.73102 |
| 70 | 0.68773 |
| 80 | 0.65476 |
| 90 | 0.63674 |
| 100 | 0.64217 |
| 110 | 0.67645 |
| 120 | 0.71737 |
| 130 | 0.76989 |
| 140 | 0.82796 |
| 150 | 0.88220 |
| 160 | 0.93996 |
| 170 | 0.98274 |
| 180 | 1.00000 |




**2**

| angle | relative_length_of_projection |
|---|---|
| 0 | 0.99974 |
| 1 | 1.00000 |
| 2 | 0.99994 |
| 3 | 0.99958 |
| 4 | 0.99892 |
| ... | |
| 91 | 0.63610 |
| 92 | 0.63570 |
| 93 | 0.63555 |
| 94 | 0.63589 |
| 95 | 0.63643 |
| ... | |
| 176 | 0.99612 |
| 177 | 0.99748 |
| 178 | 0.99854 |
| 179 | 0.99929 |
| 180 | 0.99974 |

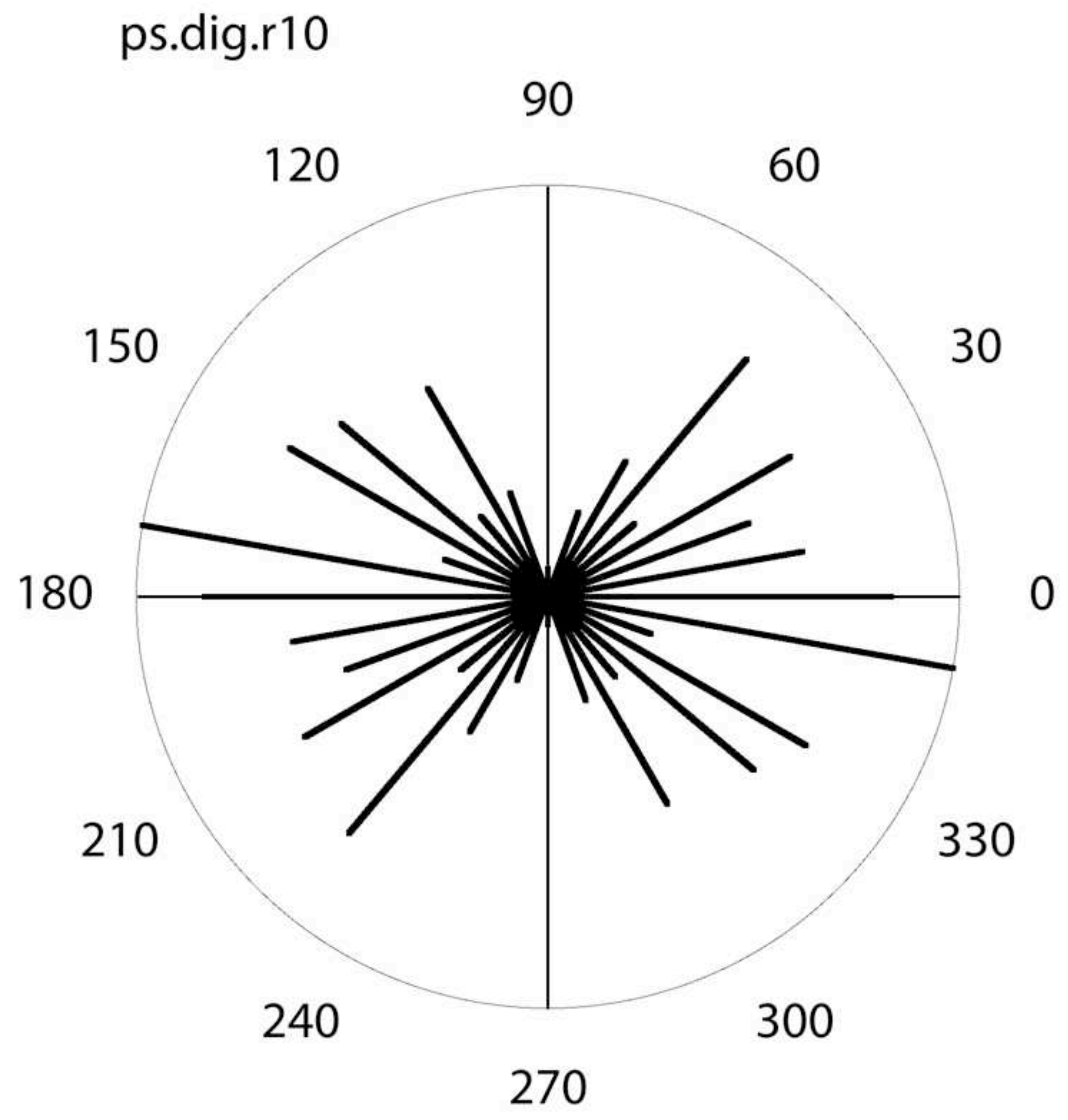



**Software Box 15.4**
SURFOR output files for different angular resolution:
(1) ps.dig.i10: values of A(α) at 10° interval and plot;
(2) ps.dig.i01: Values of A(α) at 1° interval and plot.
Using 1° increments directly yields values of $α_{min}$, $α_{max}$ and b/a.

```
 angle  length_of_s  rel.length_surface
-180.0    92.512     0.624
-177.5     0.000     0.000
-175.0    77.743     0.524
-172.5     0.000     0.000
-170.0    75.161     0.507
-167.5     0.000     0.000
-165.0   112.100     0.756
-162.5     0.000     0.000
-160.0    44.915     0.303

... etc.

160.0     46.180    0.311
162.5      0.000    0.000
165.0     75.557    0.509
167.5      0.000    0.000
170.0    148.349    1.000
172.5      0.000    0.000
175.0    118.942    0.802
177.5      0.000    0.000
180.0     92.512    0.624
```

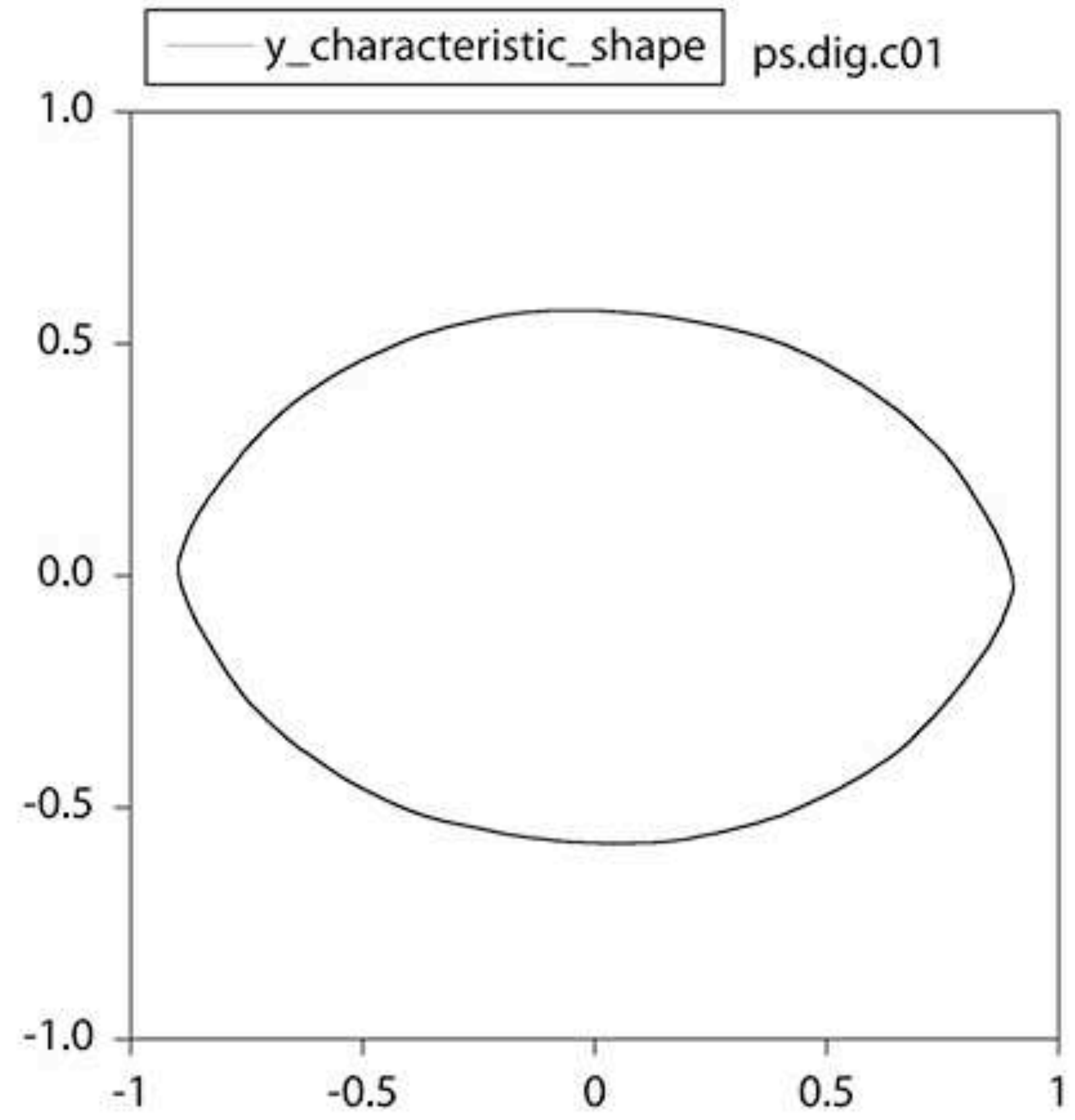



**Software Box 15.5**
SURFOR output file ps.dig.r10:
Length weighted orientation distribution of line segments and rose diagram (10° interval).

```
  x                y_characteristic_shape
 -7.1320318E-02  0.5742874
 -9.5122874E-02  0.5738578
 -9.5122874E-02  0.5738578
 -0.1157482      0.5727649
 -0.1369111      0.5712727
 -0.1554190      0.5696427
 -0.1770863      0.5673528
 -0.1770863      0.5673528


... etc.


  0.1044288      0.5669345
  8.4854394E-02  0.5690032
  8.4854394E-02  0.5690032
  4.8880663E-02  0.5715396
  3.4096763E-03  0.5739493
  3.4096763E-03  0.5739493
 -1.8278193E-02  0.5743406
 -7.1320318E-02  0.5742874
```




**Software Box 15.6**
SURFOR output file ps.dig.c01:
X-Y coordinates of characteristic shape and plot with longest and shortest projection superposed.

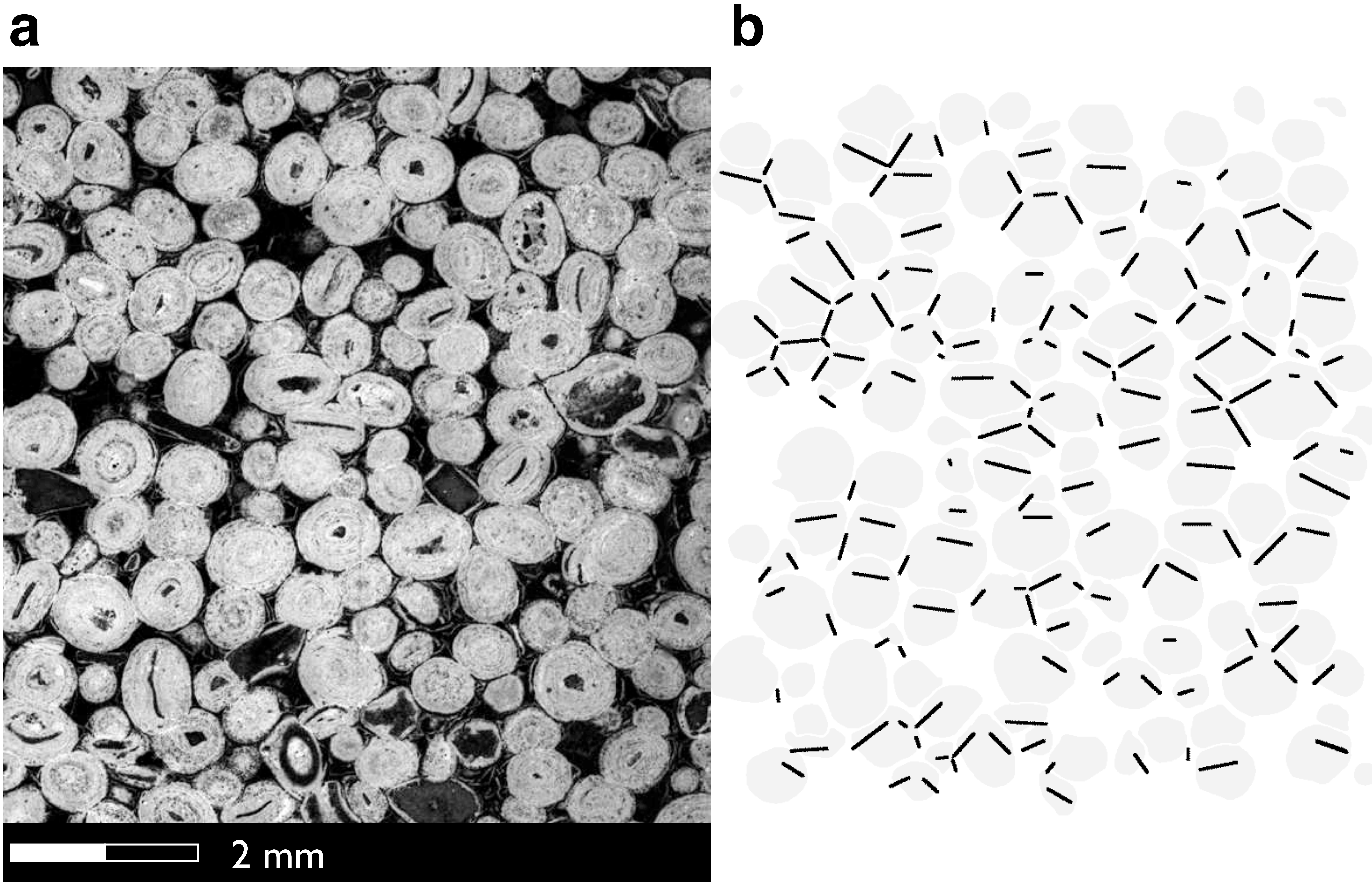



**Figure 15.3**
Example of natural surface fabric: pressure solution contacts.
(a) Micrograph of oolithic limestone with pressure solution grain-to-grain contacts (same as Figure 14.4);
(b) grain-to-grain contacts digitized as straight line segments. (Sample courtesy Samuel Mock).

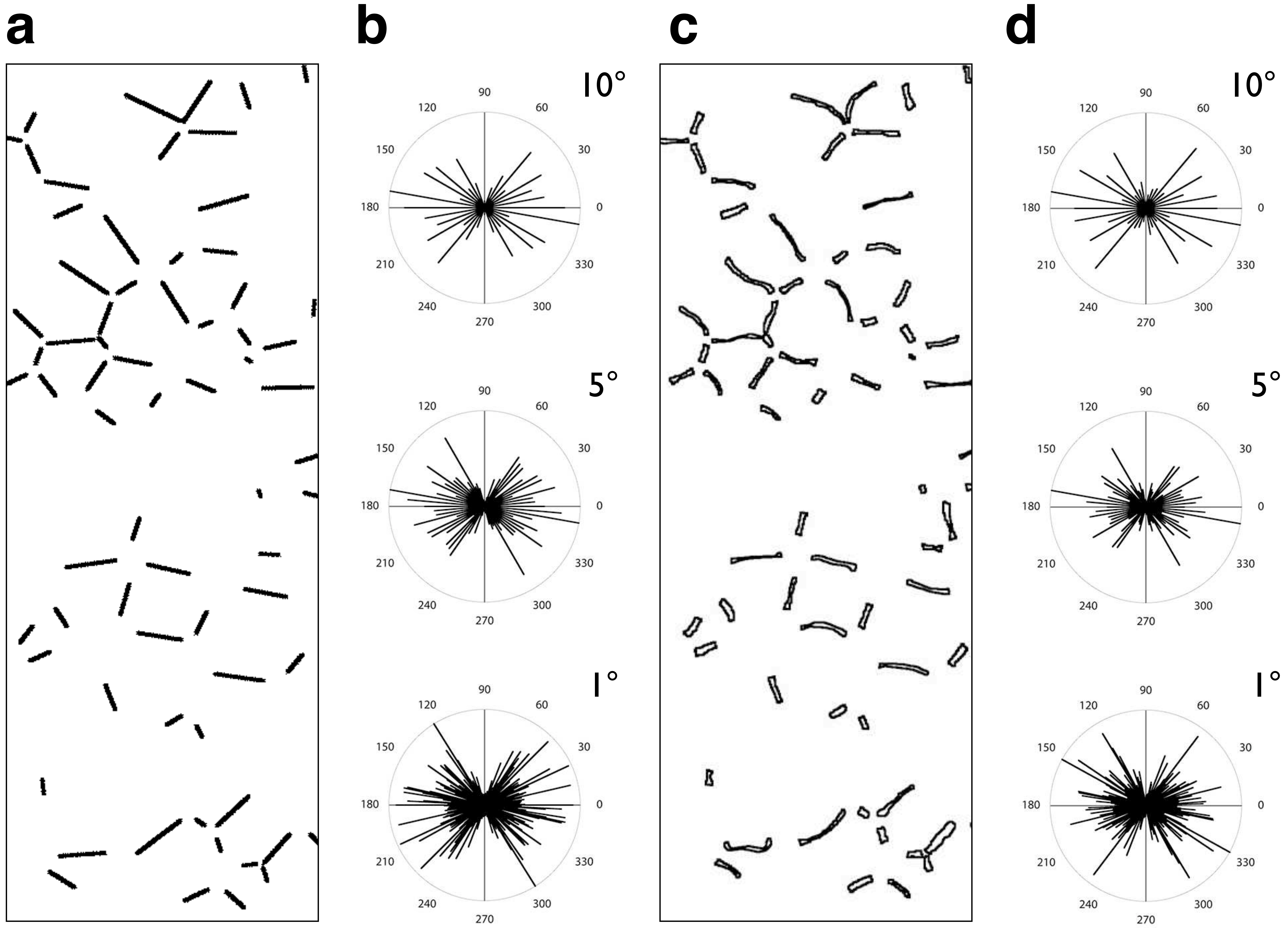



**Figure 15.4**
SURFOR and PAROR analysis of pressure solution contacts.
(a) Grain-to-grain contacts are digitized as straight line segment;
(b) ODF of line segments, evaluated with 1°, 5° and 10° intervals;
(c) outlines of areas representing the grain-to-grain contacts;
(d) ODF of long axes, $LA_2$, of outlines, evaluated with 1°, 5° and 10° intervals.

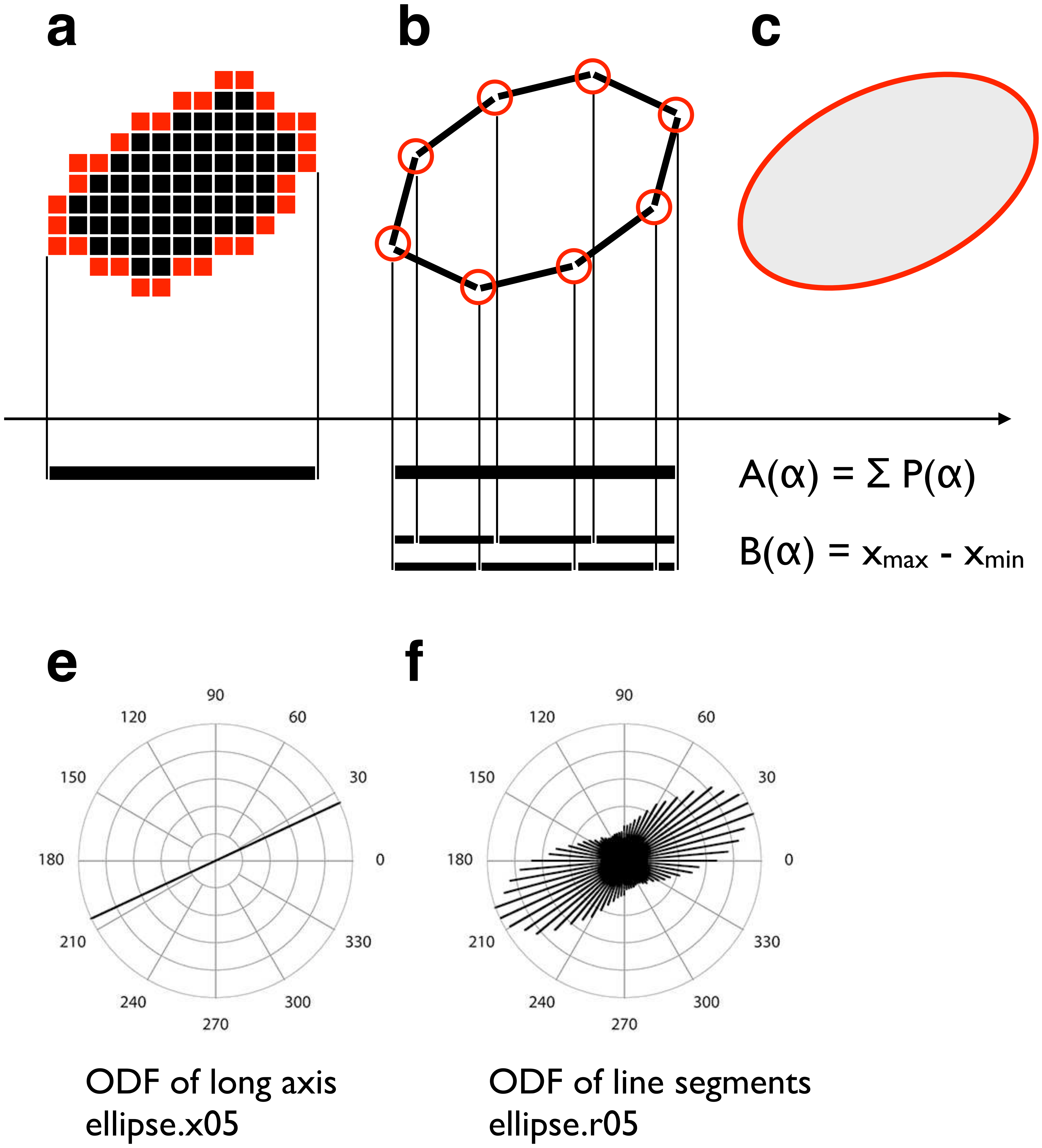



**Figure 15.5**
Surface projection versus particle projection.
Surface projection, $A(\alpha)$ = sum of projections of individual line segments; particle projection, $B(\alpha)$, = difference ($x_{max}$ - $x_{min}$) along outline. For fully convex particles, $A(\alpha) = 2 \cdot B(\alpha)$.
(a) boundary pixels of digitized area;
(b) vertices of approximating polygon;
(c) continuous outline of the original shape;
(d) PAROR rose diagram: ODF of long axis of ellipse;
(e) SURFOR rose diagram: ODF of line segments of outline.

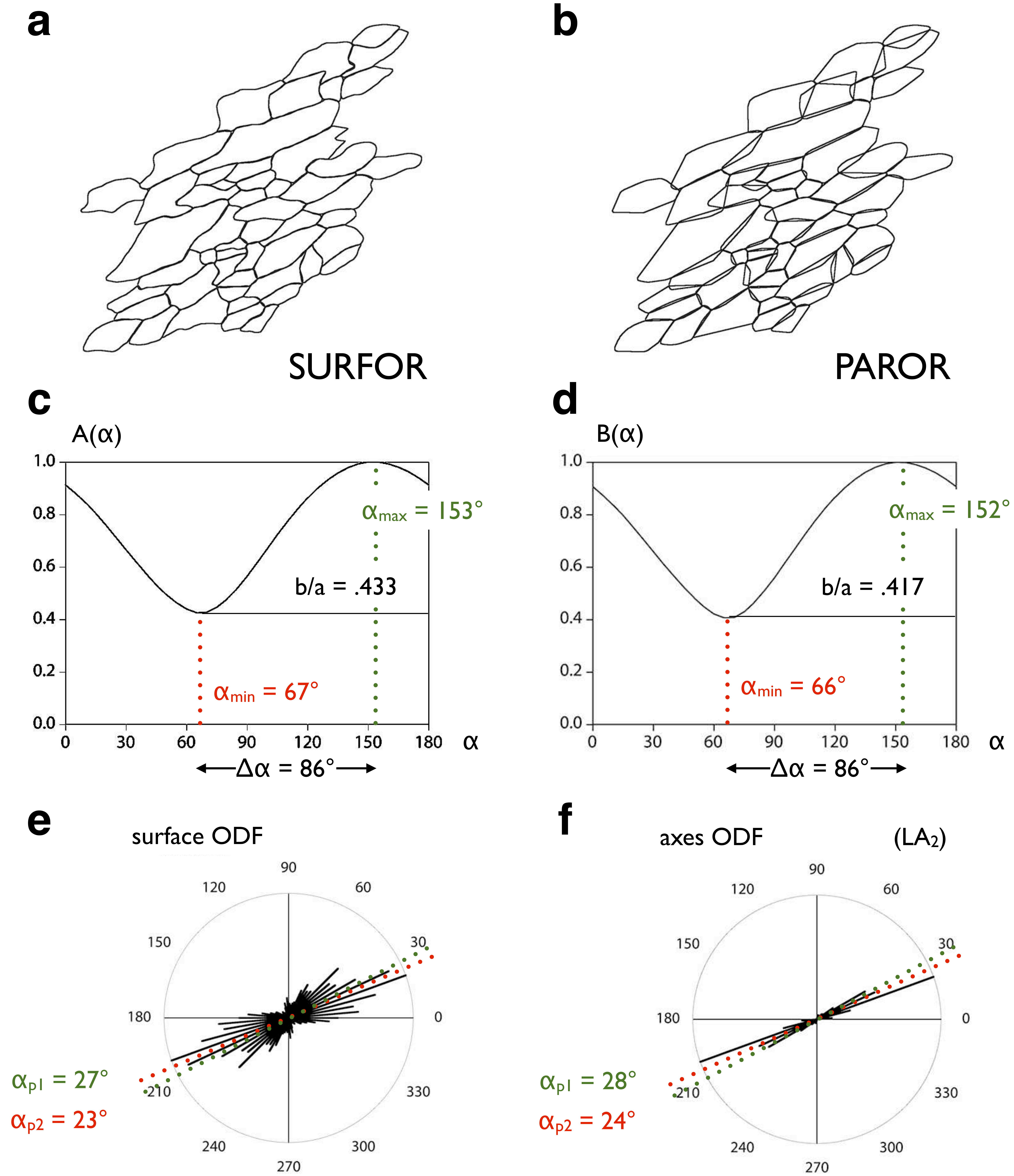



**Figure 15.6**

Comparison of SURFOR and PAROR analysis of sample CT1 (CT1.apl.scm).

Sample is from series of shearing experiments on marble by Schmid et al. (1987).

(a) Scaled and smoothed outlines, as 'seen' by SURFOR;

(b) convex hull of grains, as 'seen' by PAROR;

(c) projection curve A($\alpha$) from SURFOR projections;

(d) projection curve B($\alpha$) from PAROR projections;

(e) rose diagrams of surface ODF from SURFOR (5° resolution);

(f) rose diagrams of long axes ODF ($LA_2$) from PAROR (5° resolution).

Superposed in (c) to (f) are the preferred orientations, $\alpha_{p1}$ (red) and $\alpha_{p2}$ (green), derived from $\alpha_{max}$ and $\alpha_{min}$; the exact values for b/a, $\alpha_{min}$ and $\alpha_{max}$ were derived from analyses made with 1° increment of rotation.

| SURFOR | analysis of ct1.apl.scm | |
|---|---|---|
| 153° | $\alpha_{max}$ of A($\alpha$) | $\Rightarrow$ $\alpha_{p1}$ = 27° |
| 67° | $\alpha_{min}$ of A($\alpha$) | $\Rightarrow$ $\alpha_{p2}$ = 23° |
| 86° | $\Delta\alpha$ of A($\alpha$) | |
| 0.4333 | $A(\alpha)_{min}$ / $A(\alpha)_{max}$ = A(67°) / A(153°) ≈ $SA_1/LA_1$ | |
| 0.9980 | A(67°+ 90° = 157°) | |
| 0.4368 | A(153°- 90° = 63°) | |
| 0.4342 | A(67°) / A(157°) ≈ $SA_1/LA_2$ | |
| 0.4368 | A(63°) / A(153°) ≈ $SA_2/LA_1$ | |
| 0.4376 | A(63°) / A(157°) ≈ $SA_2/LA_2$ | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

| PAROR | analysis of ct1.apl.scm | |
|---|---|---|
| 152° | $\alpha_{max}$ of B($\alpha$) | $\Rightarrow$ $\alpha_{p1}$ = 28° |
| 66° | $\alpha_{min}$ of B($\alpha$) | $\Rightarrow$ $\alpha_{p2}$ = 24° |
| 86° | $\Delta\alpha$ of B($\alpha$) | |
| 0.4169 | $B(\alpha)_{min}$ / $B(\alpha)_{max}$ = B(66°) / B(152°) ≈ $SA_1/LA_1$ | |
| 0.4232 | B(66°+90° = 156°) | |
| 0.9985 | B(152°-90° = 62°) | |
| 0.4175 | B(66°) / B(156°) ≈ $SA_1/LA_2$ | |
| 0.4232 | B(62°) / B(152°) ≈ $SA_2/LA_1$ | |
| 0.4238 | B(62°) / B(156°) ≈ $SA_2/LA_2$ | |
| 0.3804 | average $SA_1$ of particles / average $LA_1$ | |
| 0.3856 | average $SA_1$ of particles / average $LA_2$ | |
| 0.4090 | average $SA_2$ of particles / average $LA_1$ | |
| 0.4146 | average $SA_2$ of particles / average $LA_2$ | |
| 0.3993 | average $SA_1$ / $LA_1$ of particles | |
| 0.4080 | average $SA_1$ / $LA_2$ of particles | |
| 0.4303 | average $SA_2$ / $LA_1$ of particles | |
| 0.4402 | average $SA_2$ / $LA_2$ of particles | |

**Table 15.2**
Measures of orientation (blue) and anisotropy (yellow) obtained by SURFOR and PAROR analysis of CT1.

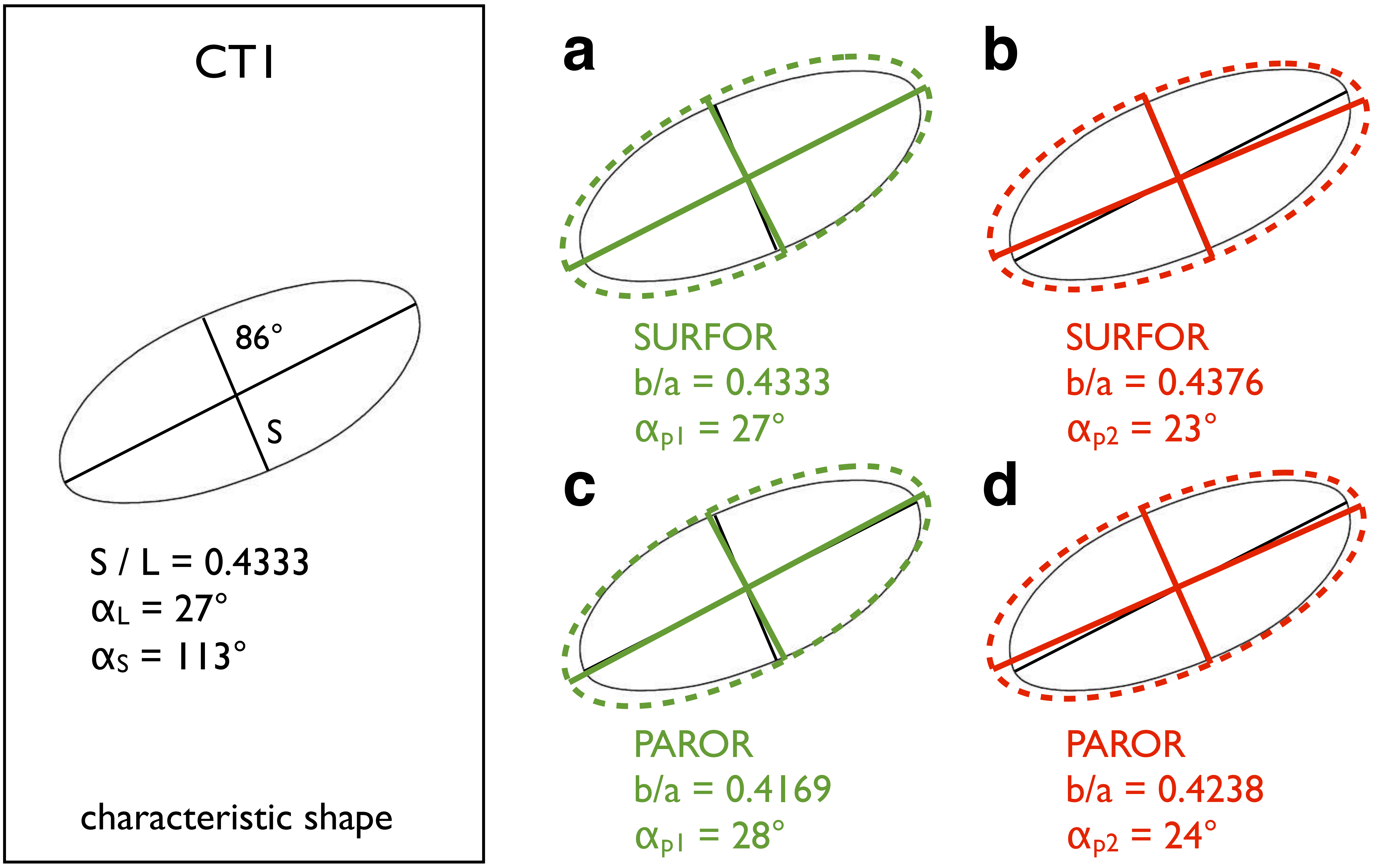



**Figure 15.7**
Characteristic shape and fabric ellipses.
Characteristic shape (file ct1.cor.c01 = 1° resolution) shown in black: the long axis (longest projection) has length $A(\alpha)_{max}$ and orientation $\alpha_L$ (= 180° - $\alpha_{max}$); the short axis (shortest projection) has length $A(\alpha)_{min}$ and orientation $\alpha_L$ (= 180° - $\alpha_{min}$); the axes are not orthogonal.
(a) Minimum ellipse (green) with axial ratio $b/a = A(\alpha)_{min} / A(\alpha)_{max}$ and orientation $\alpha_{p1}$ = 180° - $\alpha_{max}$;
(b) maximum ellipse (red) with axial ratio $b/a = A(\alpha_{max} - 90°) / A(\alpha_{min} + 90°)$ and orientation $\alpha_{p2}$ = 90° - $\alpha_{min}$;
(c) minimum ellipse (green) with axial ratio $b/a = B(\alpha)_{min} / B(\alpha)_{max}$ and orientation $\alpha_{p1}$ = 180° - $\alpha_{max}$;
(d) maximum ellipse (red) with axial ratio $b/a = B(\alpha_{max} - 90°) / B(\alpha_{min} + 90°)$ and orientation $\alpha_{p2}$ = 90° - $\alpha_{min}$.

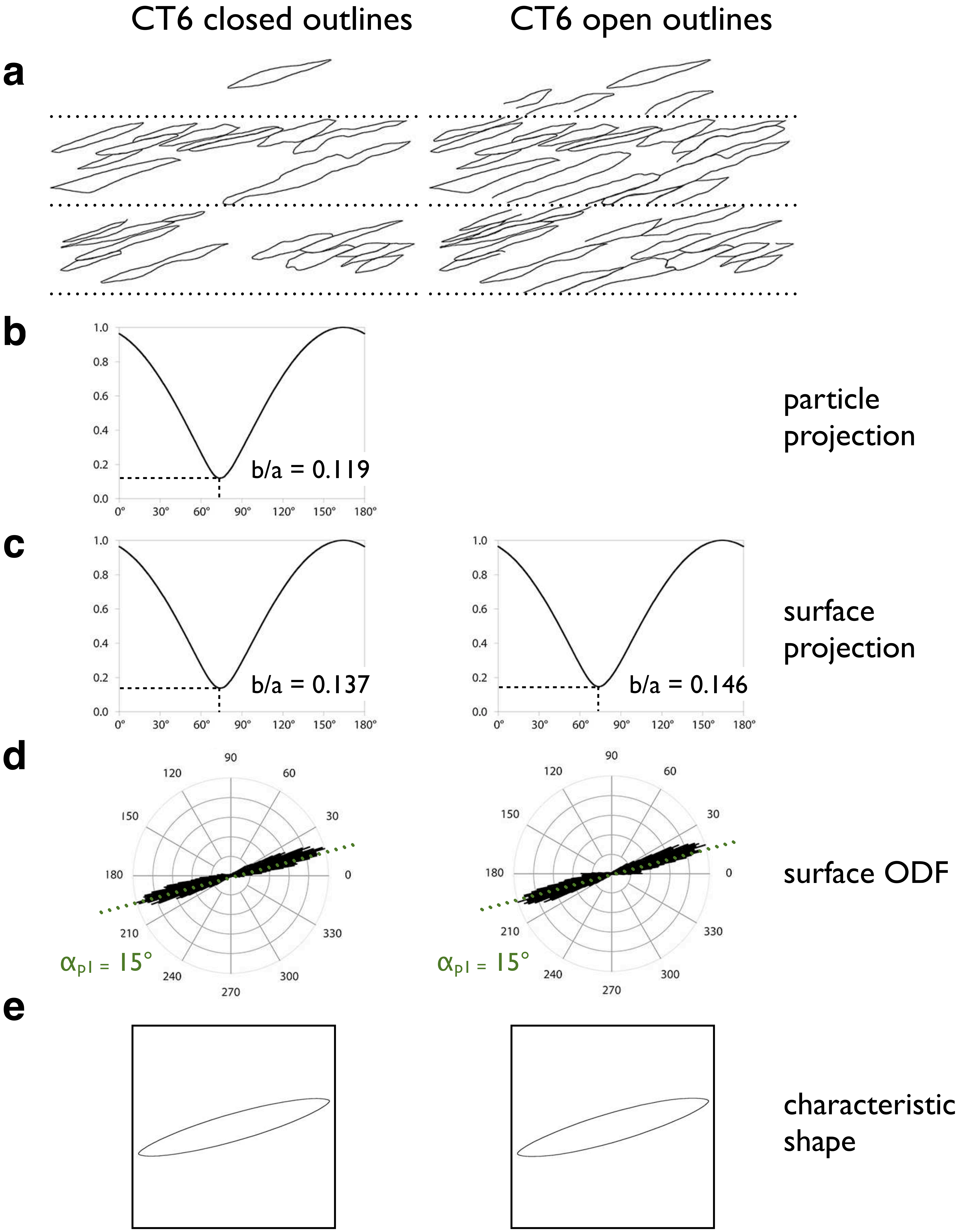



**Figure 15.8**
SURFOR and PAROR analysis of CT6.
Sample is from series of shearing experiments on marble by Schmid et al. (1987).
(a) CT6closed = closed outlines only; CT6open = open and closed outlines; three sections of the shear zone have been stacked; the shear zone boundaries are indicated by stippled lines;
(b) PAROR analysis: $B(\alpha)$ curve;
(c) SURFOR analysis: $A(\alpha)$ curve;
(d) SURFOR analysis: ODF of line segments;
(e) SURFOR analysis: characteristic shape.

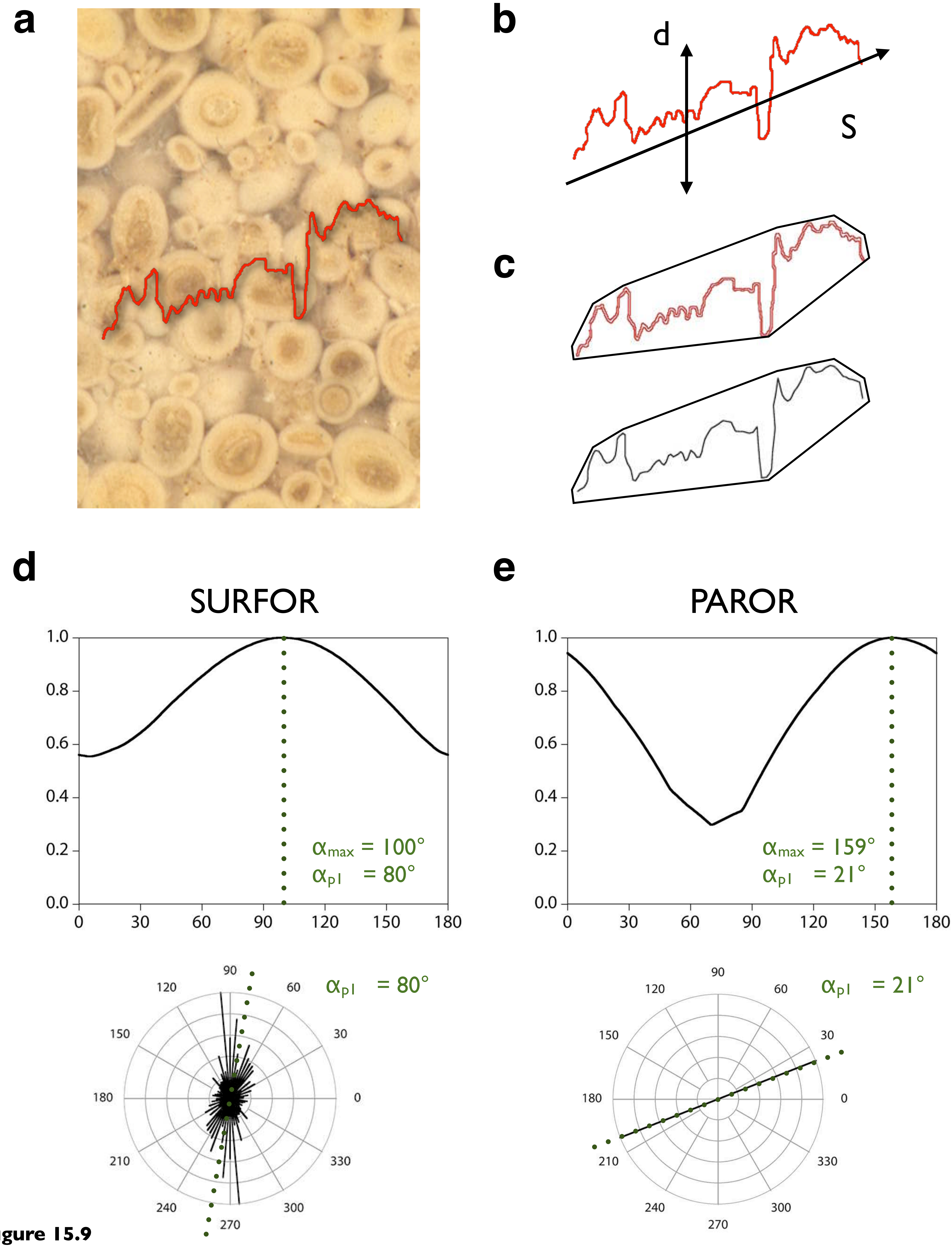



**Figure 15.9**
Stylolithic surface in oolithic limestone.
(a) Polished surface;
(b) trace of stylolite; double arrow indicates the overall orientation of the stylolite, S, and the compaction direction, d;
(c) convex hull of stylolite; stylolite represented by boundary pixels (red outline) or manually digitized (black line);
(d) SURFOR analysis of stylolithic surface; (e) PAROR analysis of stylolithic surface.

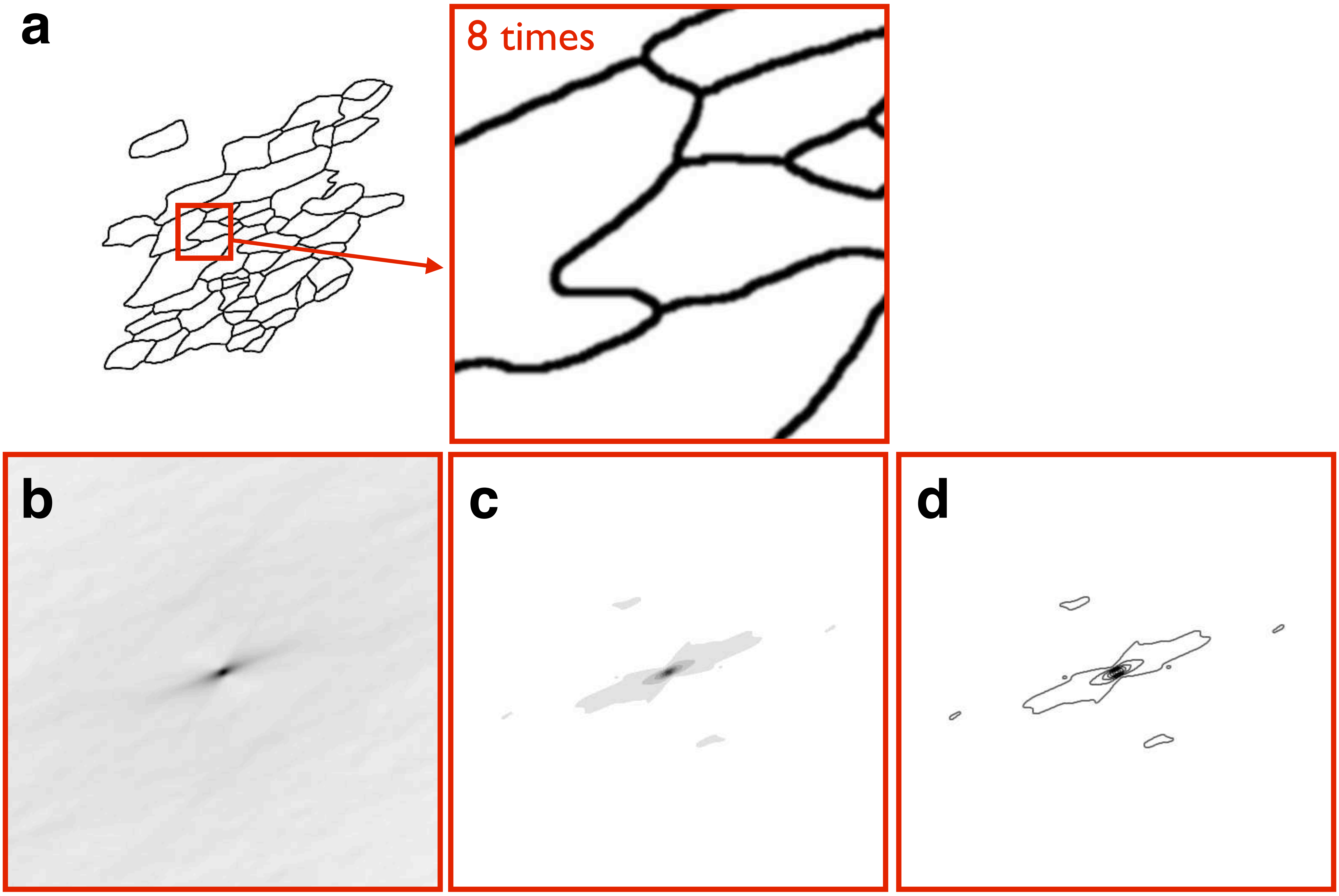



**Figure 15.10**
Replacing SURFOR analysis using the autocorrelation function (ACF).
(a) Bitmap of outlines (4096 · 4096 pixels) with enlarged detail of sample CT1;
(b) center of ACF; enlarged 8 times with respect to to (a);
(c) representation of (b) using 10 gray values only;
(d) contoured version of (b), contours at 10%, 20%, ... of $ACF_{max}$.

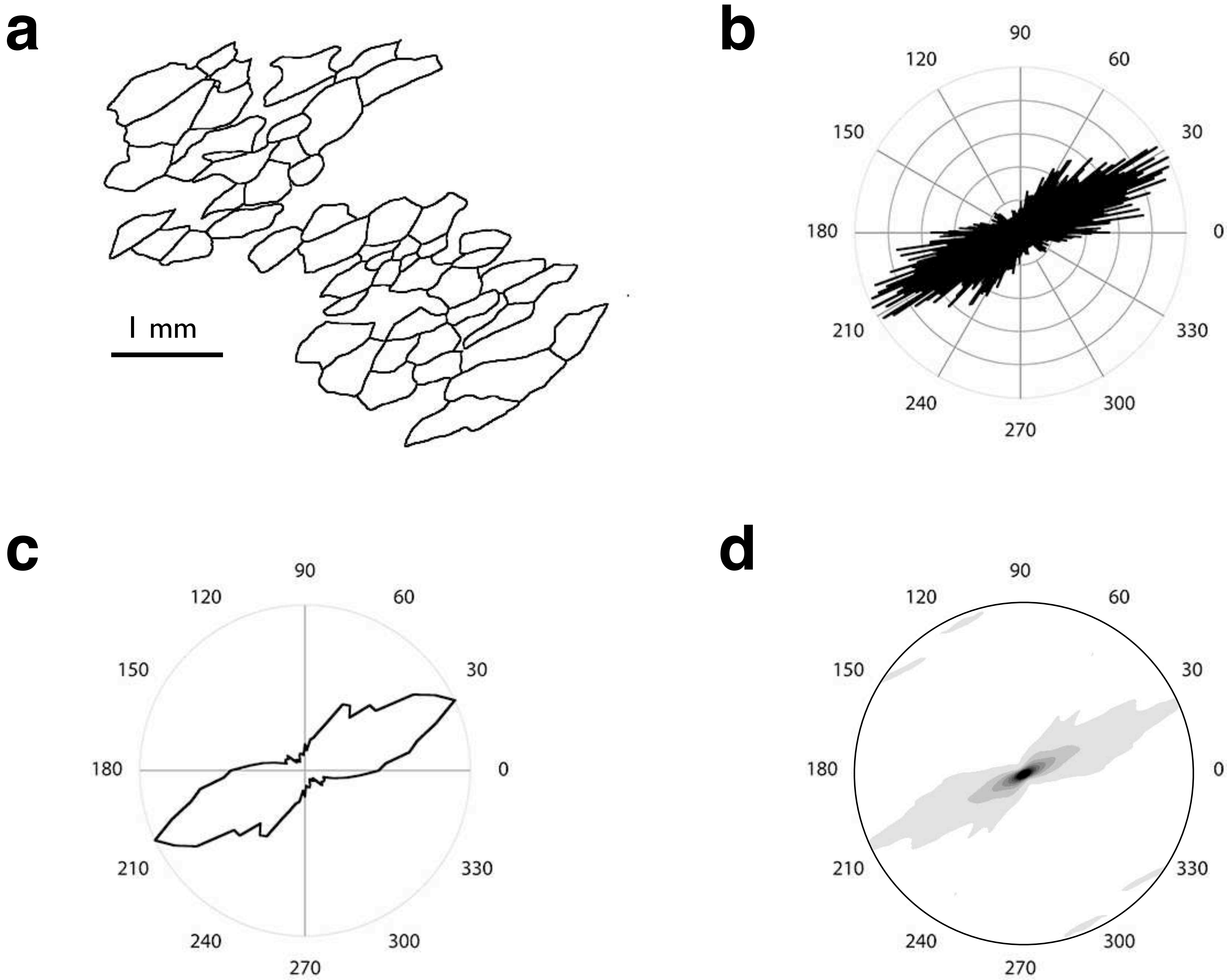



**Figure 15.11**
SURFOR and ACF analysis of CT1.
(a) Grain map (4096 · 4096 pixels); grain boundaries are 5 pixels wide;
(b) SURFOR rose diagram drawn as bar plot of relative length of line segments (1° interval);
(c) SURFOR rose diagram drawn as line plot of relative length of line segments (10° interval);
(d) ACF scaled such that the the 10% contour touches the superposed circle.