BIAXIAL REFLECTING COALS IN THE PEACE RIVER COALFIELD (93O, P, I)

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INTRODUCTION

Vitrinite has traditionally been considered to have a uniaxial negative reflectance indicatrix. The validity of common reflectance measures such as $\bar{R}_o$ max and $\bar{R}_o$ m (mean maximum and mean random vitrinite reflectance) is based on this assumption. However, an increasing number of biaxial reflectance indicatrixes are being reported from coals of various ranks from around the world (Cook, *et al.*, 1972; Stone and Cook, 1979; Hower and Davis, 1981; Levine and Davis, 1984).

The objective of this preliminary study was to examine a variety of coals from the Peace River Coalfield to determine if any biaxial reflecting coals are present, and to devise a methodology to identify these coals from particle samples.

As part of the study 19 oriented coal samples were collected from various locations in the central and northern portions of the coalfield. Sections parallel to the three major cleat planes, face, butt, and bedding, were examined for each sample. The results of these measurements are presented and discussed. In addition, two computer programs were developed to predict the results of reflectance analysis of particle samples from biaxial coals. The resulting theoretical analysis data were used to devise a useful graphical technique for indicatrix determination.

BACKGROUND

Traditionally, vitrinite has been considered to have a uniaxial negative reflectance figure. In such a figure three mutually perpendicular axes describe an oblate spheroid with the short c axis, R_o min, oriented normal to bedding, and the two remaining long a and b axes, R_o max, being equal in length and oriented in the plane of bedding (Fig. 19-1). It is assumed that as the rank of a coal increases the sheet-like aromatic molecules within the coal grow in directions normal to the maximum stress direction. Most commonly maximum stress would be due to overburden loading, therefore the coal molecules would grow in a horizontal direction (Stack, *et al.*, 1975). This process is not well understood and the physical change caused by metamorphism may indeed be a stacking of the aromatic molecules (Murchison, 1978). Irrespective of the actual physical changes, it is well documented that the maximum reflectance direction lies in all directions in the plane of bedding in areas where the maximum stress direction was vertical and normal to bedding. Figure 19-1a illustrates this situation where a = b>c. Examination of this indicatrix from any direction will yield a unique maximum reflectance value, R_o max, and a minimum reflectance value, R_o min′, that varies from the true minimum to the true maximum. Only in the case of sections normal to bedding are true R_o max and R_o min values observed. The common coal rank measure, $\bar{R}_o$ max, is based on this relationship. Any section through the indicatrix will yield the R_o max value. By taking the mean of the R_o max values from the many sections, the true value is estimated. The scatter of R_o max values being due to random measurement errors.

With a biaxial reflectance indicatrix all three principle reflectance axes are of different lengths, b>a>c (Fig. 19-1b). Only sections which contain the b axis will provide the true, R_o max, value.

Random sections of a biaxial indicatrix will not produce a normal distribution about the true maximum reflectance because there are two reflectance axes of different values being measured rather than the two axes of one reflectance value as in the case of uniaxial negative indicatrixes. Biaxial reflectance indicatrixes form where stresses other than solely overburden loading are present. It is still not understood if post-coalification stress is responsible or syn-coalification deformation or both.

ORIENTED COAL SAMPLES

Oriented coal samples from the Gates and Gething Formations were obtained from a variety of structural settings in the northern half of the coalfield (Fig. 19-2). Samples were collected from natural outcrops, mine pit walls, and adit faces. Samples consisted of coal blocks approximately 20 centimetres on a side with adequate markings so their original orientation could be restored. Three roughly perpendicular sections were obtained, one parallel to each of the three cleat directions. These small samples were mounted in cold set epoxy in 3.8-centimetre molds, and polished according to standard techniques. Sample examination was performed with a Leitz MPV3 reflecting light microscope with 546 nm wavelength light in oil with a refractive index of 1.518.

Only structureless vitrinite was used to determine reflectance values, and only if it occurred as continuous bands (vitrinite A). Traverses were made across the sample and readings taken on each vitrinite band. The maximum and minimum reflectance values along with their orientations, were recorded. Once it was established that the shape of the indicatrix on any section would be an ellipse, a more rapid measurement technique became justified. The standard procedure is to monitor the reflectance value as the sample is rotated 360 degrees on the microscope stage to determine the maximum and minimum reflectance values. The modification was based on work by Ting (1978), who described a procedure requiring three readings at a 45-degree angular separation to arrive at the maximum and minimum axis lengths of an ellipse. A variation of this procedure was employed, where five readings, each 45 degrees apart, were recorded. A computer program was written to generate three determinations of R_o max and R_o min from these five readings as well as the orientation of the R_o max reading for each determination. The three determinations from each set-up provide a means of evaluating the validity of the readings. Between three and ten set-ups were made on each section depending upon the number of vitrinite bands present. Results of these measurements are presented in Table 19-1.

Significant problems were anticipated and encountered in analysing oriented sections of coal. Other workers have had similar difficulties (Ting, pers. comm.) and some have utilized compromise techniques (Stone and Cook, 1979). Several reasons for these problems are:

(1) sections may not be oriented exactly as desired, which is particularly important when dealing with the bedding plane section;
(2) different vitrinite bands may be encountered on difference sections;

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1985, Paper 1986-1.

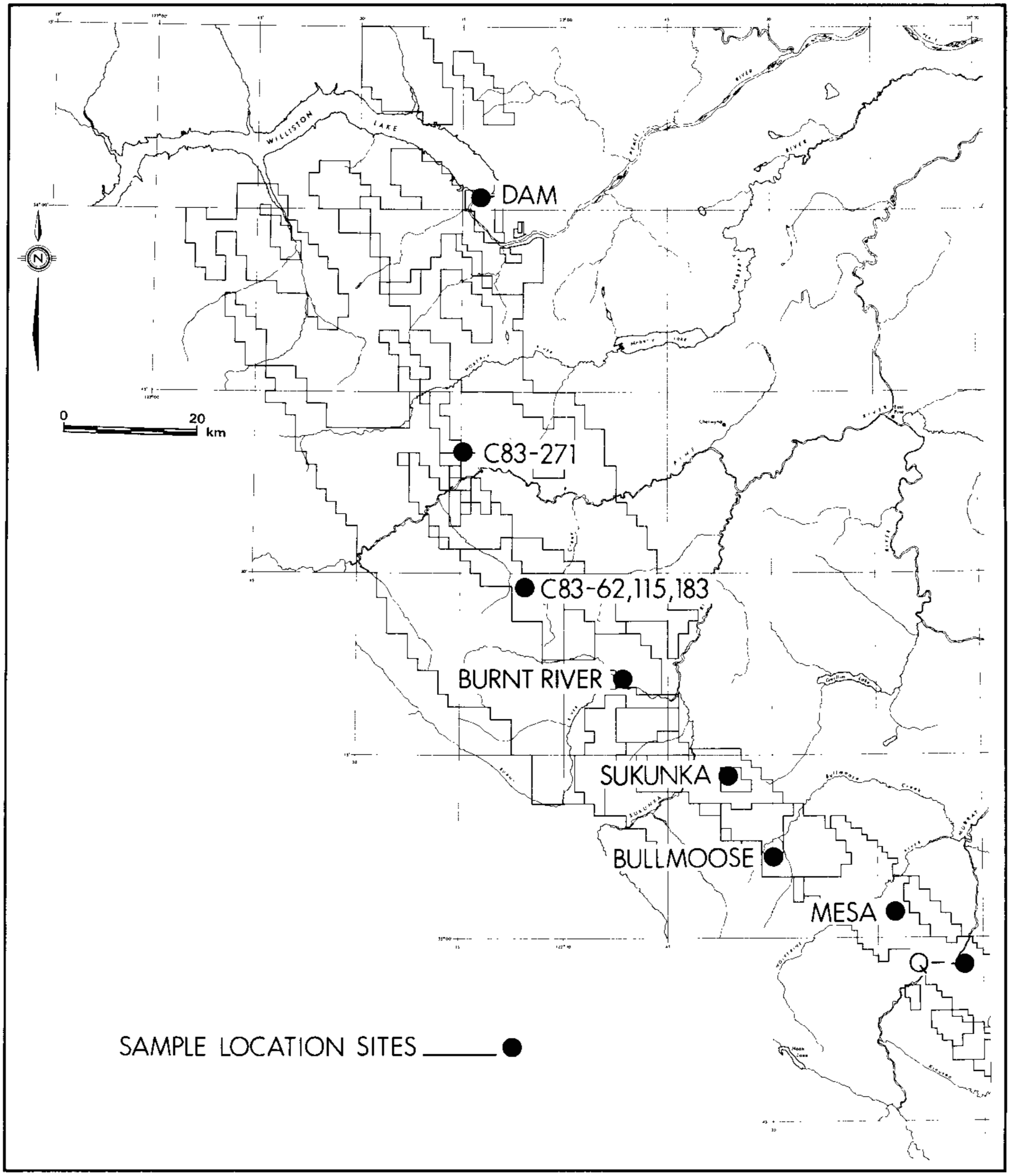

Figure 19-2. Location map of oriented sample collection sites.

TABLE 19-1
VITRINITE REFLECTANCE VALUES OBTAINED FROM THREE MUTUALLY PERPENDICULAR SECTIONS CUT THROUGH ORIENTED COAL SAMPLES

Sample No.	Bed Max	Bed Min	Bed Bi	Face Max	Face Min	Face Bi	Butt Max	Butt Min	Butt Bi	Formation
Peace River										
DAM	1.56	1.43	0.13	1.48	1.13	0.35	1.54	1.08	0.46	Lower Gething
Burnt River										
BR-60	1.81	1.56	0.25	1.62	1.24	0.38	1.72	1.35	0.37	Lower Gething
BR-U	1.82	1.71	0.12	1.72	1.38	0.34	1.83	1.42	0.38	Lower Gething
Sukunka	1.43	1.35	0.09	1.40	1.19	0.20	1.39	1.19	0.19	Upper Gething
Bullmoose										
Bull 84A	1.30	1.22	0.08	1.27	1.10	0.17	1.13	1.01	0.15	Gates
A1	1.18	1.11	0.07	1.27	1.05	0.22	1.25	1.10	0.14	Gates
A2	1.26	1.18	0.08	1.34	1.08	0.26	1.22	1.06	0.16	Gates
Bull 84B	1.20	1.11	0.09	1.21	1.10	0.25	1.28	1.15	0.13	Gates
B1	1.21	1.11	0.11	1.21	1.07	0.13	1.20	1.01	0.19	Gates
B2	1.25	1.21	0.05	1.25	1.04	0.22	1.23	1.01	0.22	Gates
Bull 84C	1.27	1.16	0.11	1.27	1.10	0.18	1.20	1.08	0.12	Gates
Bull 84E	1.06	0.97	0.08	1.02	0.89	0.13	1.05	0.93	0.11	Gates
E1	1.13	1.07	0.06	1.12	0.92	0.20	1.15	0.97	0.17	Gates
Quintette										
Mesa L	1.47	1.39	0.08	1.43	1.14	0.29	1.33	1.11	0.21	Gates
Q8202	1.48	1.35	0.12	1.45	1.20	0.24	1.44	1.17	0.28	Gates
Q8203	1.34	1.25	0.09	1.12	0.96	0.16	1.16	0.97	0.19	Gates
Q8204	1.58	1.51	0.07	1.55	1.29	0.26	1.51	1.22	0.29	Gates
Q8501	1.50	1.37	0.13	1.45	1.23	0.22	1.47	1.18	0.28	Gates
SQ108	1.48	1.35	0.13	1.39	1.15	0.24	1.43	1.25	0.18	Gates

(3) due to the plastic nature of coal, multiple vitrinite orientations may be present on a single section;
(4) only one vitrinite band is encountered on the bedding plane section and its values may not coincide with the mean values of the other sections.

Stone and Cook (1979), in an effort to overcome the problems associated with the bedding plane section, used four sections cut normal to bedding to calculate a bedding plane section of the indicating surface (CBPSIS). The results of their procedure were often non-elliptical shapes which may be due to the technique. In this study, all actual bedding plane sections had good elliptical reflectance distributions.

Examination of the average bireflectance value (difference between R_o max' and R_o min') on each section aids in interpreting the shape of the indicatrix. If the bedding cleat section contained two equal reflectance axes, the bireflectance would be zero or very small due to random errors. Indeed this value, with a few exceptions, is much smaller on the bedding section than on the face or butt sections (Table 19-1). This suggests that the bedding section is quite close to the orientation of the a-b plane in most cases.

In addition to obtaining the reflectance values from each section, the orientations of the maximum apparent reflectance axis were determined. As noted in Table 19-1, all samples had some bireflectance on the bedding plane section. When the orientation of the maximum reflectance direction on the bedding section was compared to the cleat orientation, it was found to fall between the two cleat directions. In the few samples where the face and butt cleats were distinctly non-perpendicular, the maximum reflectance direction bisected the acute angle between the cleat traces.

The orientation of the maximum reflectance values from the bedding sections of two Burnt River samples, BR-U and BR-60, are parallel, with an azimuth of about 135 degrees. The maximum reflectance direction on the face cleats trends down slightly to the south, and the maximum reflectance direction on the butt section is parallel to bedding. These samples were collected from seams about 60 metres apart stratigraphically and about 400 metres apart laterally. The presence of similarly oriented indicatrixes which are not aligned parallel to bedding is a strong argument for syn or post-tectonic coalification in this area. When the reflectance values of the three sections of sample BR-U are plotted on an isometric block (Fig. 19-3), they are consistent with a biaxial indicatrix (Fig. 19-1b)

In samples with bedding plane bireflectances near those obtained from the sections normal to bedding, one of two explanations must be assumed given that the section is in fact oriented parallel to bedding:

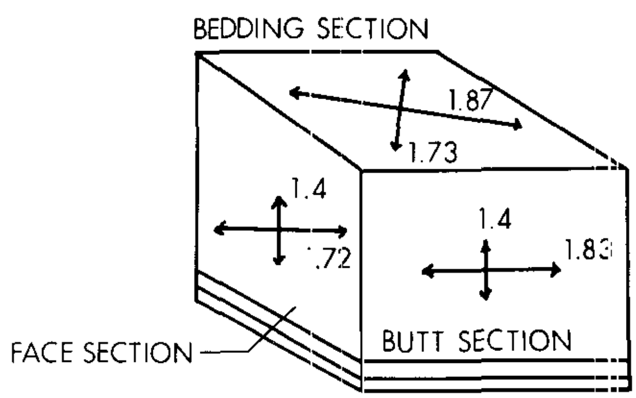

Figure 19-3. Schematic representation of the reflectance readings obtained from sample BR-U.

(1) If the bedding section maximum reflectance is similar to the maximum values from the other two sections, then the indicatrix is not aligned with bedding — a strong argument for post-tectonic coalification.

(2) If the maximum reflectances from the face and butt cleats fall between the maximum and minimum bedding reflectance values, the sample likely has a biaxial reflectance indicatrix.

A trend of undetermined significance is present between the Bullmoose and Quintette samples. The bedding section maximum from the Quintette samples is in all cases larger than the maximum values obtained on the other two sections. At Bullmoose the bedding plane maximum is, with two minor exceptions, equal to or less than the maximum values obtained from the face and butt cleat sections.

Oriented samples provide the means to determine the orientation of reflectance indicatrixes but are fraught with problems when trying to determine the absolute values of the indicatrix. The heterogenous nature of coal and the variability of vitrinite reflectance values all lead to data that is often difficult to interpret. Because of these problems and the additional sample collection and preparation requirements, it was desirable to develop a method of determining if a sample had a biaxial reflectance pattern from data obtainable from the standard particle samples.

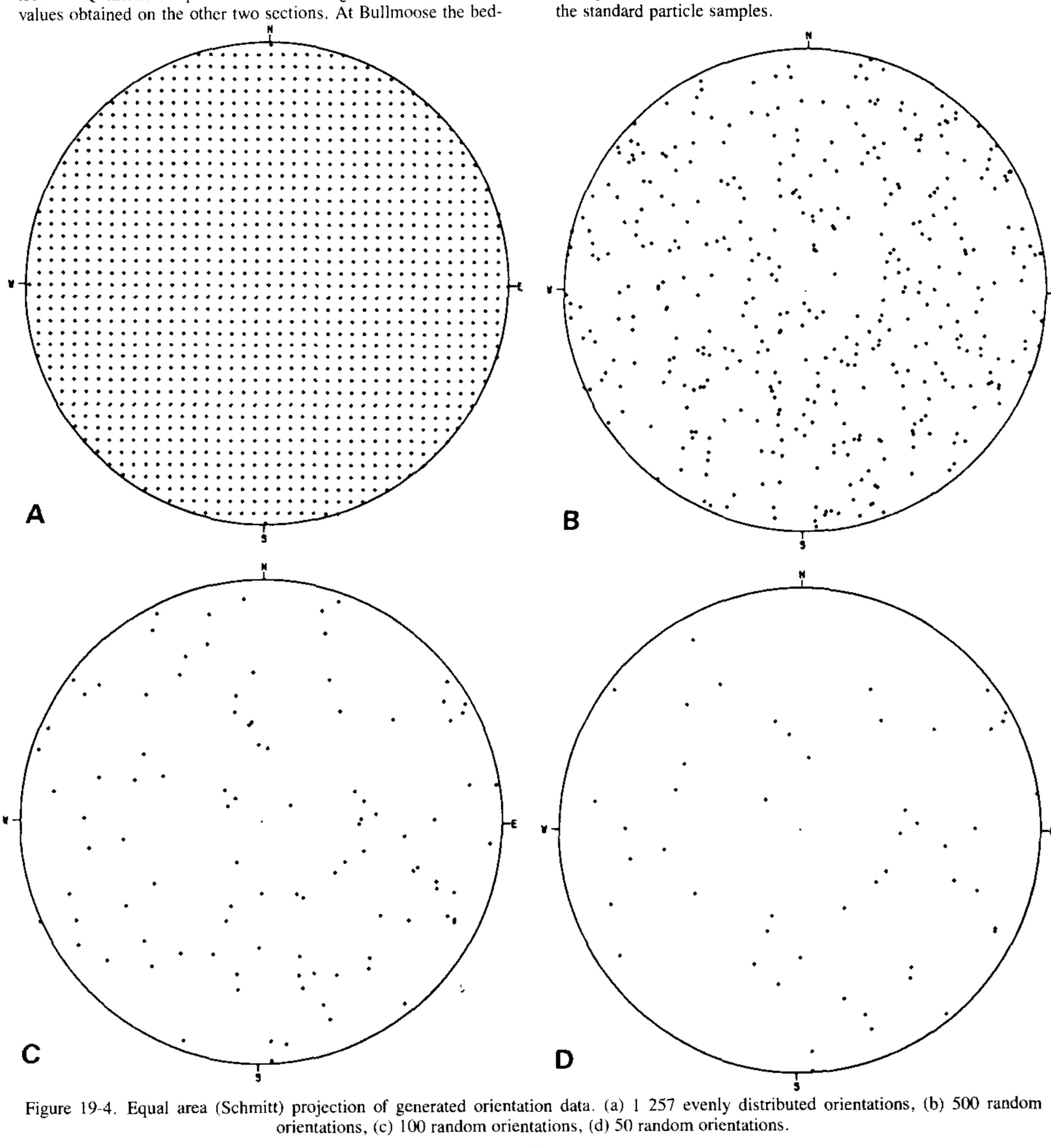

Figure 19-4. Equal area (Schmitt) projection of generated orientation data. (a) 1 257 evenly distributed orientations, (b) 500 random orientations, (c) 100 random orientations, (d) 50 random orientations.

THEORETICAL PARTICLE SAMPLE INVESTIGATION

To investigate various statistical and graphical techniques for their ability to discern biaxial coals from particle samples, test data was required. Particle samples consist of crushed coal (−20 mesh) held in a mounting medium of epoxy or plastic. One surface is polished and examined. This polished surface intersects many coal particles, each with no predefined orientation (random). Two computer programs were designed to simulate the results of this type of analysis on coal with different reflectance indicatrixes. RANDATA generated various sized populations of random orientations. These orientations represented the random orientations at which the polished surface of a mount would cut individual coal grains and thus the reflectance indicatrix. Four different sized populations are displayed on equal area projections on Figure 19-4. Hypothetical reflectance indicatrixes were simulated in the program BI-COAL. This program accessed the desired file of random orientations and calculated what the maximum and minimum reflectances would be on the sections corresponding to these orientation data. The reflectance values for the three axes were used to define the shape of the indicatrix, and a standard deviation value was entered to account for naturally occurring variance in measurements.

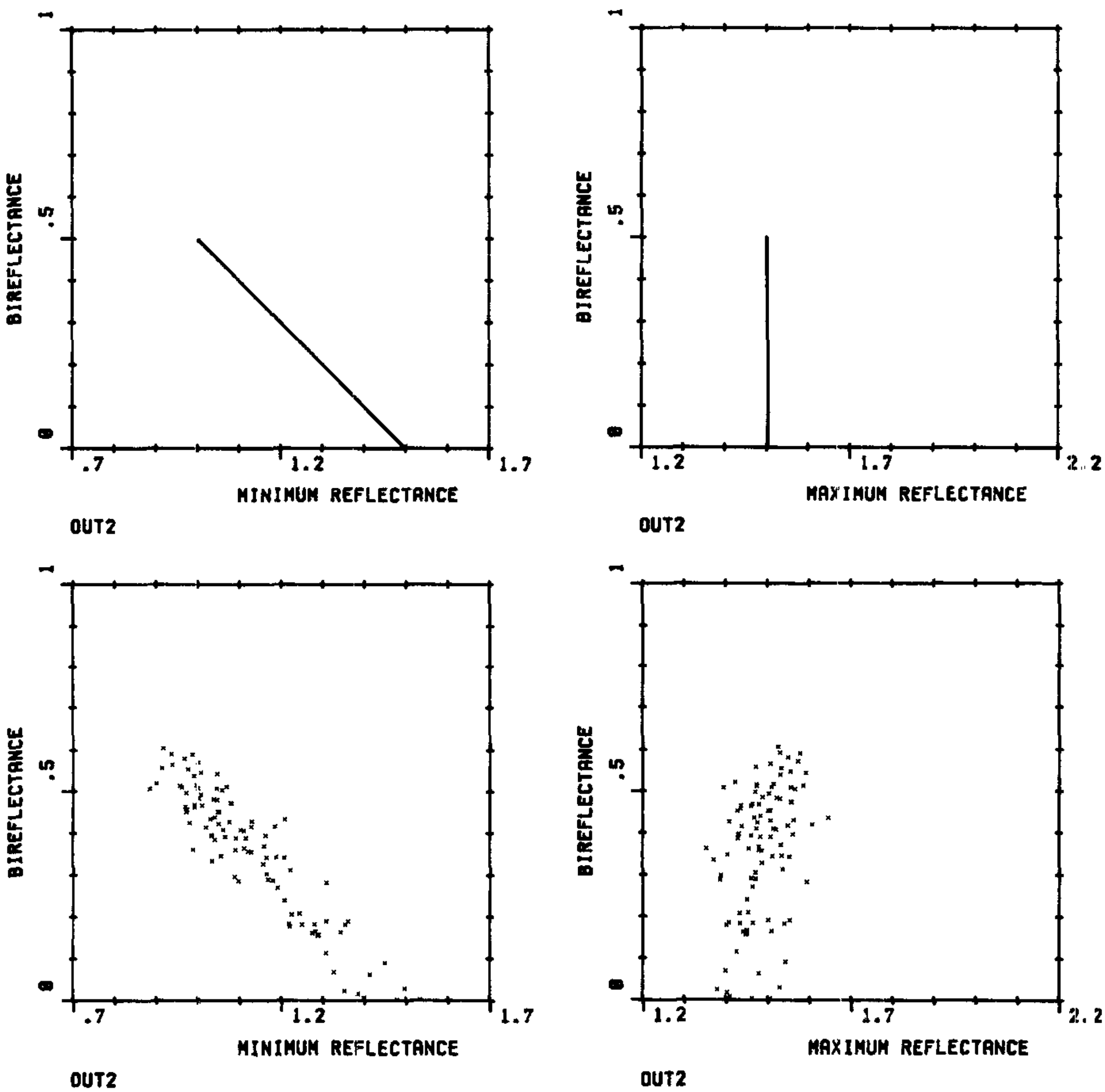

Figure 19-5. Uniaxial negative indicatrix reflectance data. a = 1.5%, b = 1.5%, c = 1%. (a) theoretical with no variance, (b) theoretical with 0.05% standard deviation and 100 random sections.

Histograms have traditionally been used to examine the maximum reflectance populations. Histograms produced by a variety of indicatrix shapes have some distinctive non-gaussian shapes but if large measurement variances are present these shapes are easily disguised. Cumulative frequency plots have often been used to check for normality of reflectance reading populations, but they were found to be difficult to interpret for biaxial populations. The best interpretation tool was a combination of two cross-plots (Figs. 19-5 and 19-6). These two plots have the bireflectance (R_o max'–R_o min') plotted on the abscissa, and the maximum and minimum reflectances plotted on the two ordinate axes. To insure clarity in this paper each sample is represented by these two plots. In practice the two data distributions would be posted on one cross-plot but with distinctive symbols so they could be visually separated.

Data from a uniaxial negative population would form a straight line on each plot (Fig. 19-5). On the R_o bi (bireflectance) versus R_o min' (minimum reflectance) plot, the line would have a negative slope and run from the R_o max value and zero bireflectance to the R_o min value and a bireflectance equal to R_o max–R_o min. The R_o bi versus R_o max' (maximum reflectance) plot has a vertical line with horizontal coordinate equal to R_o max and a vertical distribution from zero to the maximum possible bireflectance (R_o max–R_o min). In natural populations the data points would be normally scattered about these two lines. Figure 19-5b shows the effect of a standard deviation of 0.05 per cent reflectance.

Theoretical biaxial populations produce plots in which data points fall within zones defined by parallelograms rather than on discrete lines (Fig. 19-6). The horizontal dimension of the zones correspond to the possible range of values between the relevant reflectance axes, a-c difference for the R_o bi versus R_o min' plot and a-b difference for the R_o bi versus R_o max' plot. The vertical dimensions correspond to the difference between the previously mentioned axes. The parallelogram shaped zones which describe the data distribution in the two cross-plots are mutually dependent with regard to their dimensions. The two zones share a common boundary which represents the R_o int value. The diagonal edges of the zones must be at 45 degrees. The areas of the two zones must be equal. The upper bounding diagonal lines of each plot share a common x-intercept with the vertical non-common boundary of the other plot. Due to the ellipsoidal shape of the indicatrixes and the fact that not all sections will contain a maximum reflectance value, the data have higher probabilities of plotting in certain portions of the parallelograms. The combination of these two plots allows the values of the three reflectance axes to be accurately determined. The intermediate axis value is determined first, then the maximum and minimum values can be determined by utilizing two measurements. The absolute values of R_o max and R_o min can be read off the horizontal scales and cross-checked by the fact that the horizontal widths of the two zones at any bireflectance value must be equal.

Examination of the R_o bi versus R_o max' plot illustrates whether a population is uniaxial negative (the most common form). This plot would show a vertically oriented band of data points normally distributed about a central line (Fig. 19-5b). If the band of points has a slope, it is indicative of either a uniaxial positive or biaxial reflectance indicatrix; both situations are anomalous and deserve additional investigation. The R_o bi versus R_o max' plot from a biaxial negative indicatrix could be confused with a uniaxial negative figure depending upon the amount of random error and the R_o int–R_o max difference. But the two should be distinguishable by the form of the data distribution about a central vertical line. A uniaxial negative population will be concentrated at the centre, while a biaxial positive population will tend to be concentrated along the vertical edges and across the top (Figs. 19-5b and 19-6c).

Histograms of the maximum reflectance values obtained from the generated populations plotted on Figures 19-5 and 19-6 are given on Figure 19-7. The shapes of these histograms can be distinctive as in the case of the biaxial neutral and biaxial negative data but when random error is included many of the subtleties of the histogram shapes are destroyed. The cross-plot displays are affected to a much smaller extent (Fig. 19-8).

PARTICLE SAMPLES

Four particle samples from previous stratigraphic studies were selected for re-examination on the basis that their histogram patterns were either bimodal or had broad peaks, which suggested the presence of a biaxial reflectance indicatrix. A particle sample was also prepared for sample BR-U because oriented section work had shown it to be a biaxial reflecting coal.

Fifty vitrinite particles were examined for each sample with R_o max' and R_o min' values being recorded. Histograms and the two cross-plots (R_o bi versus R_o min' and R_o bi versus R_o max') were prepared and interpreted (Fig. 19-9).

Interpretation of the cross-plots for sample BR-U duplicated the results previously obtained by the oriented section technique. The sample is biaxial negative with a reflectance indicatrix having the following dimensions: a = 1.70 per cent, b = 1.89 per cent, c = 1.35 per cent. The histogram from this sample is obviously bimodal.

Sample C83-62 had a well-defined, bell-shaped histogram pattern of R_o max' values but the cross-plots show distinctly that the sample is biaxial positive (Fig. 19-9b). Determined reflectance axes values for this sample are: a = 1.51 per cent, b = 1.70 per cent, c = 1.41 per cent.

Sample C83-115 produced a histogram distribution of R_o max' values which had a very wide peak (Fig. 19-9c). The R_o bi versus R_o max' cross-plot had a distribution pattern best described by a positively sloping zone and was thus not uniaxial negative. A small maximum bireflectance of 0.2 per cent made interpretation of this sample difficult. The R_o bi versus R_o min' plot could be interpreted as scatter about a vertical line at 1.35 per cent R_o min'. This would mean a uniaxial positive indicatrix with dimensions: a = 1.17 per cent, b = 1.37 per cent, c = 1.17 per cent. The author prefers the biaxial positive interpretation with indicatrix dimensions of a = 1.25 per cent, b = 1.35 per cent, c = 1.16 per cent.

Sample C83-183 has a broad poorly peaked histogram shape (Fig. 19-9). The cross-plots suggest a biaxial negative reflectance indicatrix with axis dimension of a = 1.68 per cent, b = 1.90 per cent, c = 1.40 per cent.

Sample C83-271 had a well-peaked, bell-shaped R_o max' distribution (Fig. 19-9e). The cross-plots show the sample to be biaxial negative with reflectance axes dimensions of a = 1.32 per cent, b = 1.42 per cent, c = 1.20 per cent.

All five particle samples examined were prepared from single piece grab samples or chip samples representative of thin seams. The four samples with identifier prefixes of C83- were from borehole core samples. This method may produce difficult to interpret results if used with samples representing large seams due to potential reflectance variance between vitrain bands through the seam which could cause a scatter of readings greater than the inter-axis values.

CONCLUSIONS

This preliminary study documents the existence of medium and low-volatile bituminous coals with biaxial reflectance indicatrixes in the Peace River Coalfield. A technique was developed to accurately determine the character and dimension of reflectance indicatrixes from standard particle samples.

Significant problems were realized in trying to calculate indicatrix dimensions from oriented sections but the oriented section method does provide excellent information regarding the orientation of the indicatrix. A combination of the two methods used here provides an excellent description of the reflectance indicatrix characteristics. The coal particle examination technique described here provides a rapid and accurate technique for identifying and quantifying the reflectance character of biaxial coals.

Future work will concentrate on documenting the biaxial reflecting coals and their use in interpreting the structural and thermal histories of coal deposits.

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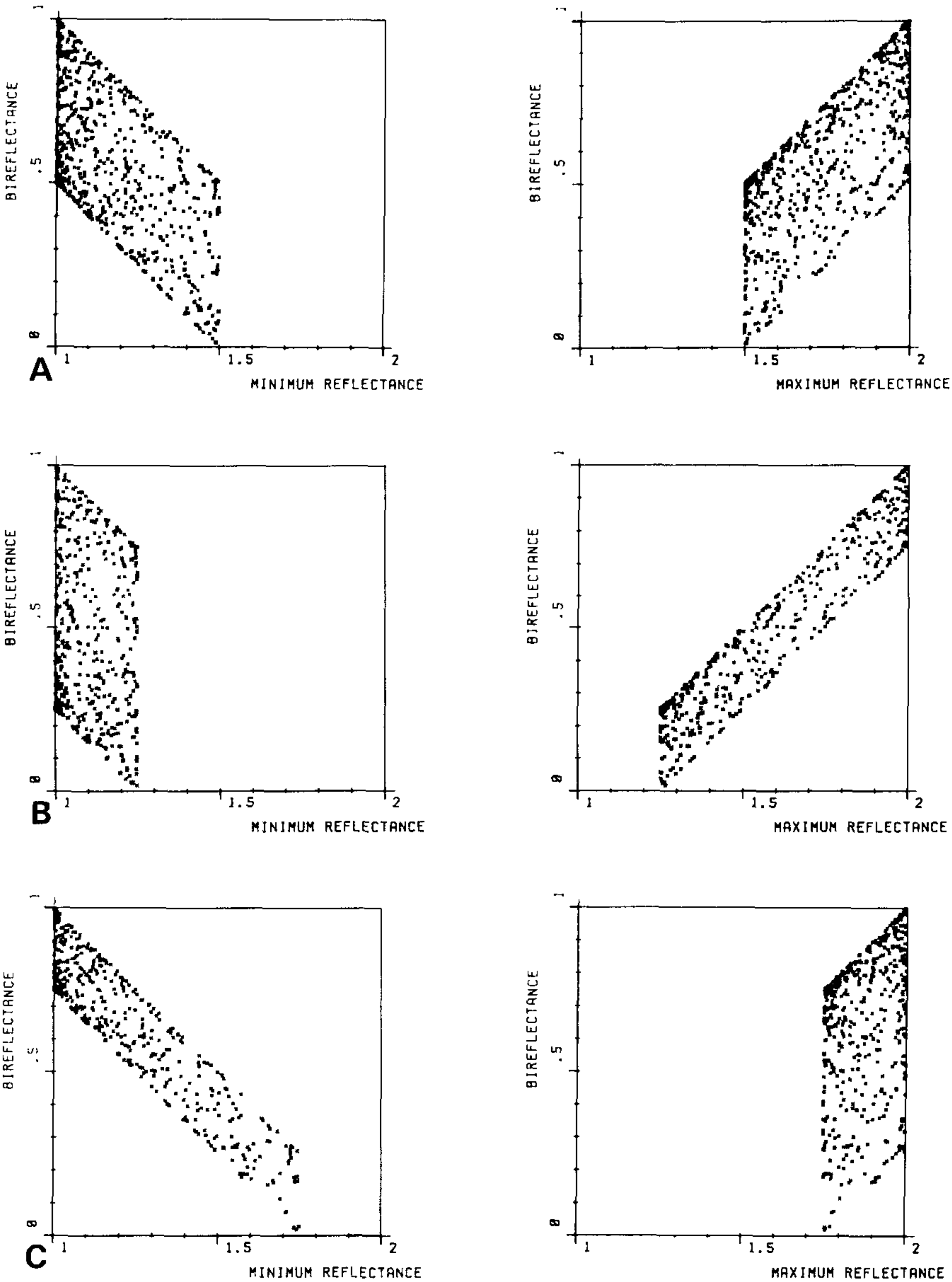

Figure 19-6. Cross-plot displays of three reflectance indicatrixes generated with randomly oriented data populations of 500 points. (a) a = 1.5, b = 2, c = 1, biaxial, standard deviation = 0; (b) a = 1.25, b = 2, c = 1, biaxial (+), standard deviation = 0; (c) a = 1.75, b = 2, c = 1, biaxial (−), standard deviation = 0.

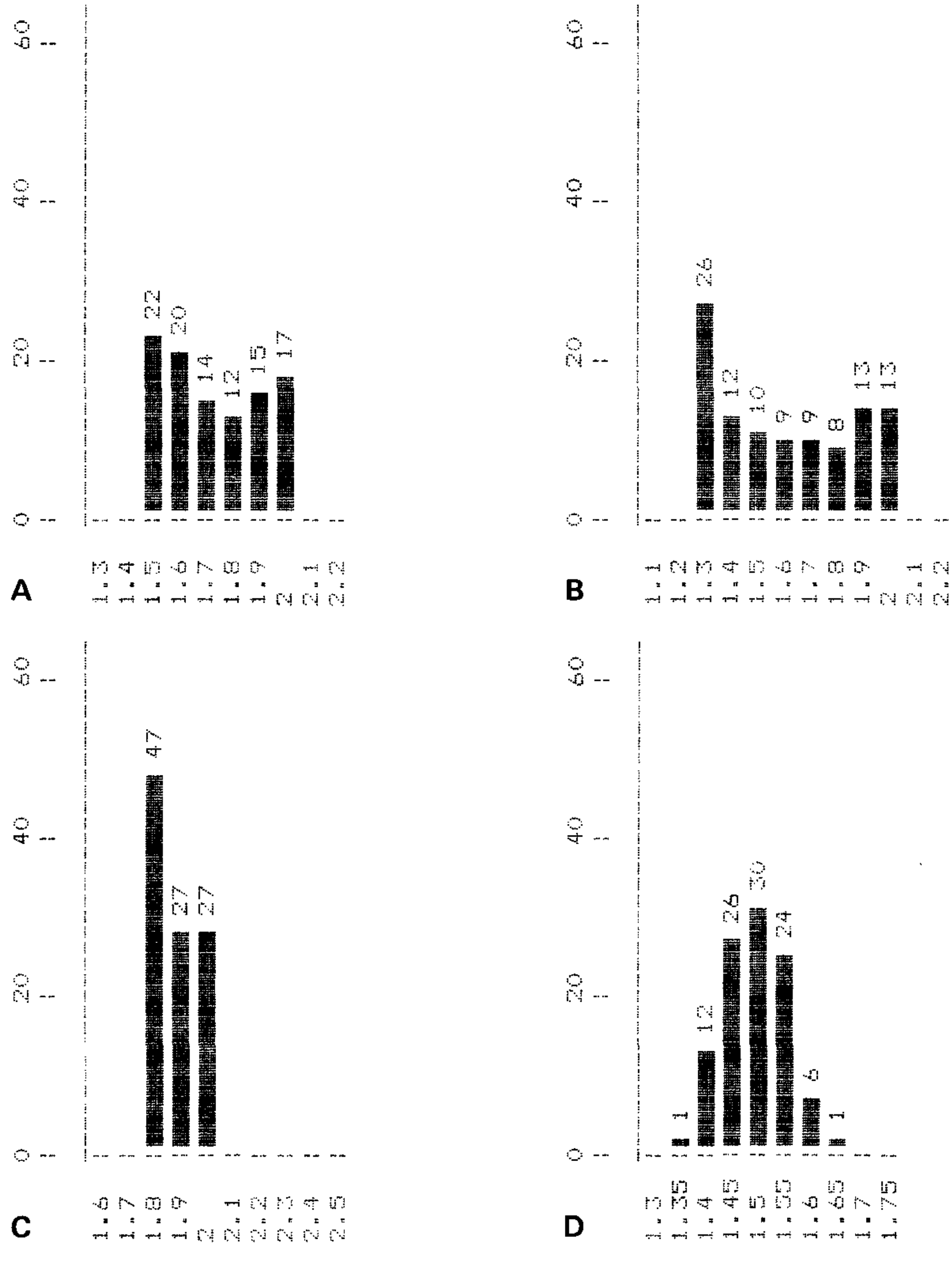

Figure 19-7. Histograms of generated data. (a) a = 1.5, b = 2, c = 1, biaxial, standard deviation = 0, 500 points; (b) a = 1.25, b = 2, c = 1, biaxial (+), standard deviation = 0, 500 points; (c) a = 1.75, b = 2, c = 1, biaxial (−), standard deviation = 0, 500 points; (d) a = 1.5, b = 1.5, c = 1, unaxial (−), standard deviation = 0.05%, 100 points.

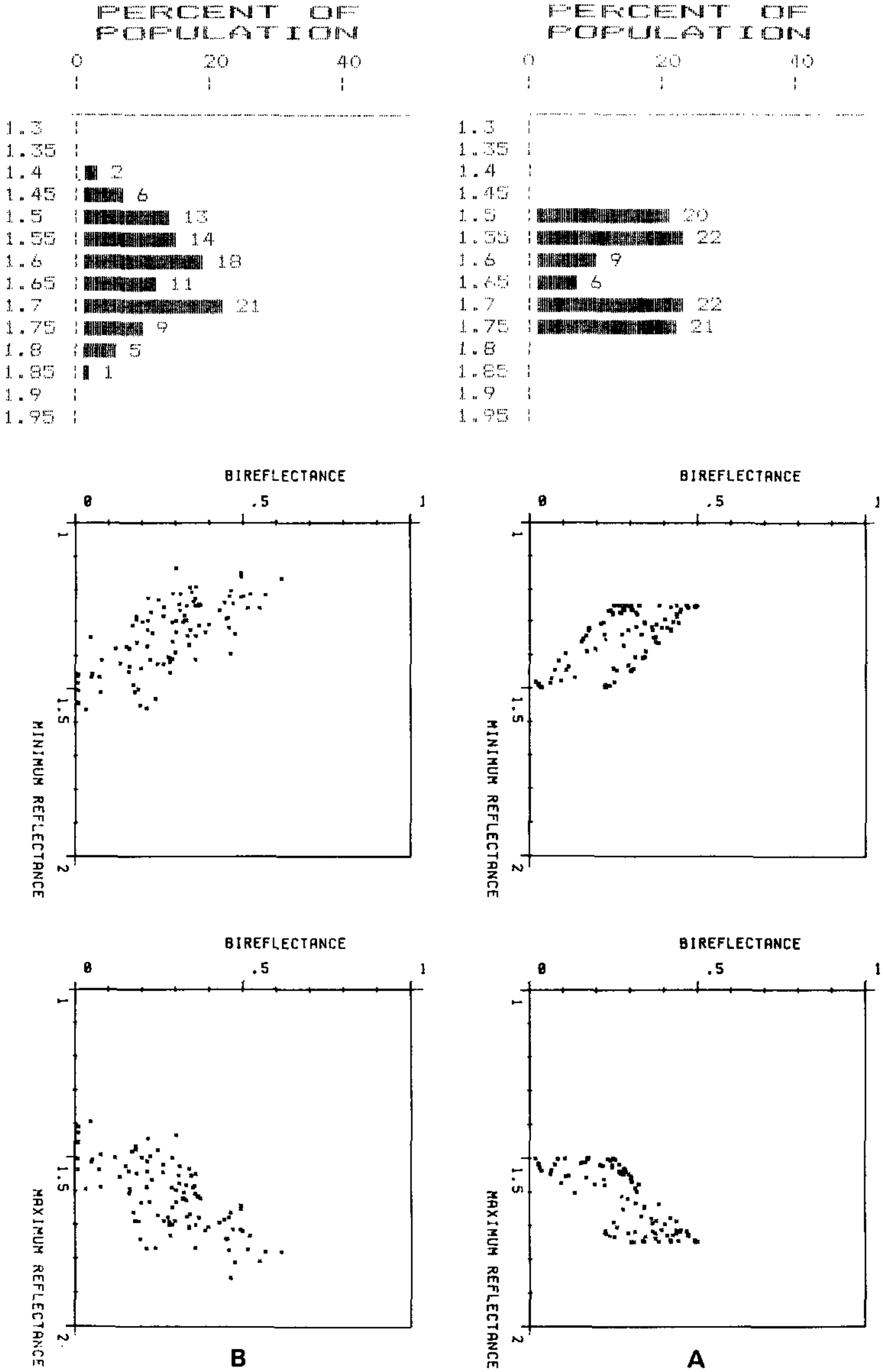

Figure 19-8. Histograms and cross-plots for biaxial reflectance distribution (a = 1.5, b = 1.75, c = 1.25). One with no variance (a) and the other with 0.05% standard deviation (b).

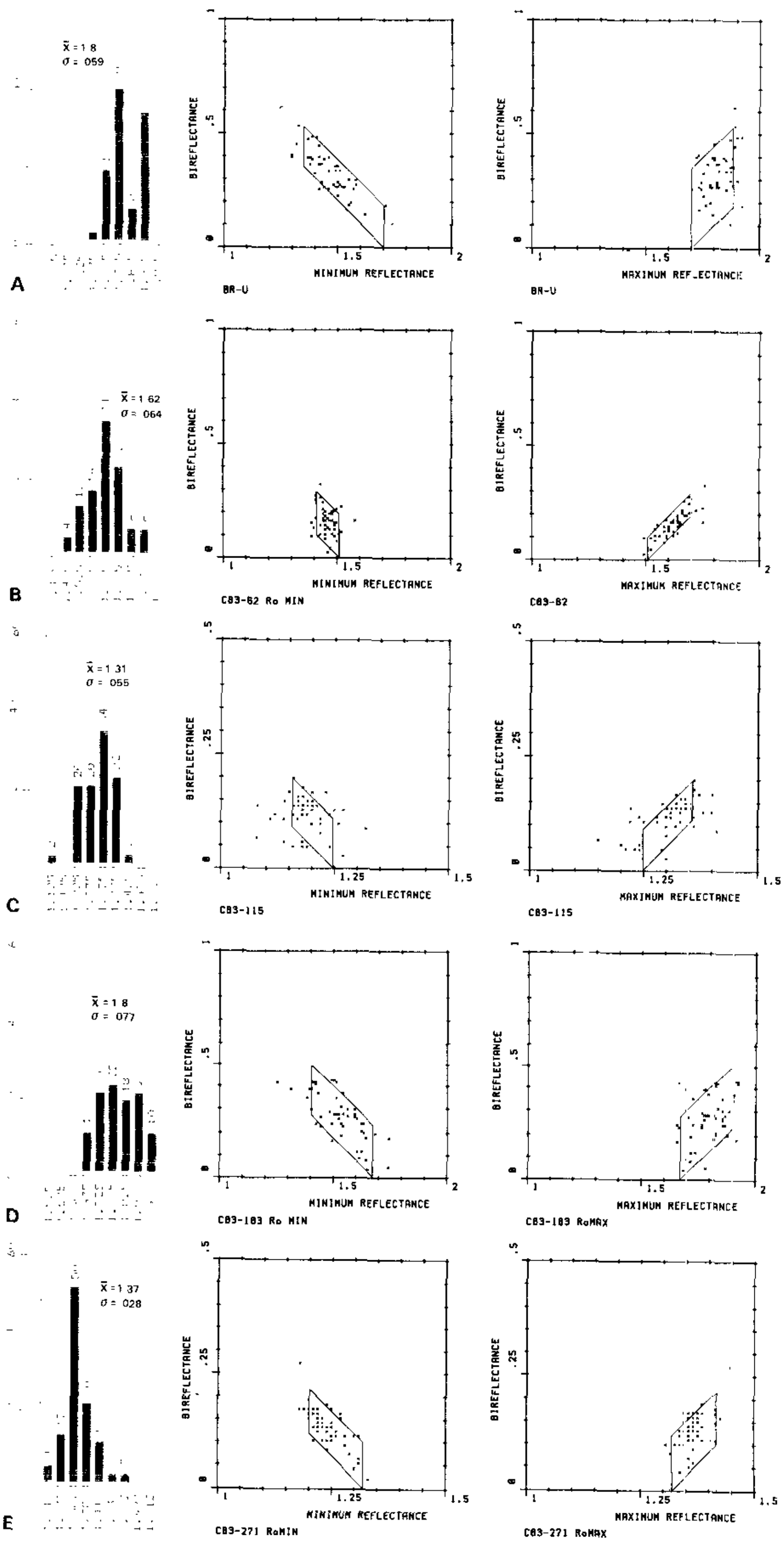

Figure 19-9. Histograms and cross-plots of particle samples. (a) BR-U, (b) C83-62, (c) C83-115, (d) C83-183, (e) C83-271.