A REFLECTANCE STUDY OF CERTAIN COALS FROM THE BOKARO COALFIELD, BIHAR

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Reflectivity measurements have been made on 25 randomly selected samples of coal of which 13 belong to the Kargali, 7 to the Karo and 5 to the Kuju seams. The Kargali and Karo seams of East Bokaro and the Kuju seam of West Bokaro are the most important seams of this coalfield and so have been chosen for this study. Reflectivity values, like those of carbon and fixed carbon, suggest a variation of rank in these coals. While the Kuju coals (R_0, 0·67 per cent) are meta-lignite, Kargali (R_0, 0·92 per cent) and Karo (R_0, 1·25 per cent) coals are para- and ortho-bituminous, respectively. There is a tendency of reflectance values to cluster round certain regularly spaced peaks, though several secondary peaks particularly between component Nos. 4 and 7 have been noticed. The evidence gathered is largely in favour of Seyler's stepwise variation of reflectance. The validity of Seyler's grouping hypothesis is further confirmed by a statistical test—the lumped variance test. The somatic pattern in some typical bright and dull coals has also been studied and a relation has been observed between the frequency of components (N_R) present and the type of coal.

INTRODUCTION

The reflectance study of coal is receiving an increasing attention these days. This method helps in understanding not only the physical properties of coal but also its rank. Several important contributions by various workers have been made on this subject in the last three decades in different parts of the world and interesting conclusions have been derived (Hoffman and Jenker 1933; Seyler 1943, 1952; Dahme and Mackowski 1950; McCartney 1952; Mukherjee 1952; Huntjens and Van Krevelen 1954; Broadbent and Shaw 1955; Siever, 1957). But to the best of the author's knowledge no substantial study on these lines has been undertaken on Indian coals so far. The only known contribution on the reflectivity of Indian coals is that by Mukherjee (1961) who recently made measurements on a few samples of Jharia XIV seam, which has been affected by igneous intrusion. The present study on the Bokaro coals, therefore, seems to be the first serious attempt in this direction. The coals under investigation belong to the three important seams, the Kargali, Karo and Kuju. While Kargali and Karo seams belong to the East Bokaro coalfield, the Kuju seam belongs to the West Bokaro coalfield.

It was with the discovery of microphotometer by Prof. Berek in 1930 (*see* Stach 1949, p. 158) that coal petrologists became increasingly interested in the quantitative assessment of reflectance. Using the Berek slit-photometer, Hoffman and Jenker (1933) observed that the reflectance increased continuously with the increase of rank. Seyler (1943) undertook a painstaking study and extending his observation to a large number of coals of different rank advanced a theory which has attracted considerable attention. Seyler stated that the constituents of coal derived from wood or bark, excluding spores, cuticles and resins, have reflectances that vary discontinuously and can be arranged in a fixed series of nine steps in a geometric progression. The $R_0 = 0{\cdot}26 \times 1{\cdot}36\ N_R$, where N_R is the number of component, from 1 to 9. Seyler's results, startling as they are, have initiated considerable interest and several attempts have been made to test the validity of his conclusions.

Dahme and Mackowski (1950) and McCartney (1952) have cast doubts on the validity of Seyler's results. They have observed a more or less gradual gradation of reflectance values with change in rank. Siever (1957) went a step further and observed that not only vitrinite but even the semifusinite and micrinite demonstrate a continuous process of variation of reflectance. Sherlock (1951) and Mukherjee (1952) working independently, however, agree with Seyler's discontinuous series. The reflectance studies of Huntjens and Van Krevelen (1954) are specially interesting. Although they observed the stepwise progression of reflectance, 'well-defined accumulations around Seyler's types Nos. 4 and 5 could not be demonstrated'. Recently Broadbent and Shaw (1955) attempted a statistical approach to the problem and in the light of lumped variance test scrutinized the accumulated reflectance data. As a result of this test and also on the basis of new data these authors proposed that variation in reflectance is more or less continuous with rank, thus supporting the views expressed by Dahme and Mackowski (1950) and McCartney (1952). Seyler and Chandra (1955), however, have revealed various anomalies in the approach of these authors and have once again justified the validity of stepwise variation.

An interesting part of reflectance studies, therefore, is to observe the manner of reflectance variation. Accordingly one of the aims of the present study is to ascertain the validity of Seyler's theory of discontinuous variation of reflectance. Besides this, the study helps in establishing the rank of these coals.

Geologic Setting

The Bokaro coalfield lies between 23° 45′ and 23° 50′ N. latitude and 85° 30′ and 86° 03′ E. longitude in the district of Hazaribagh, Bihar. It covers an area of 572 sq km and includes a narrow belt of Gondwanas extending 65 km from east to west and 10 to 16 km from north to south.

East and west are the two subdivisions of the coalfield separated by the Lugu hill (ht. 960·9 m) which stands majestically almost in the middle of the field.

The Gondwana rocks, comprised of the Talchir, Damuda and Panchet series, rest on and are surrounded by the Archaeans. The Barakars, which cover a greater part of the coalfield, are the chief coal-bearing strata. Eight productive coal seams, 5 belonging to the East Bokaro coalfield and 3 to the West Bokaro coalfield, are known to occur. The various coal seams in their downward succession are as follows:

East Bokaro coalfield

12-foot A seam	3 m
Jarangdih seam	6 m
Kargali seam	30 m
Bermo seam	13 m
Karo seam	24–30 m

West Bokaro coalfield

Kuju seam	12 m
No. XI seam	9 m
No. X seam	6 m

Although the Kargali and Karo seams of East Bokaro and the Kuju seam of West Bokaro are amongst the most productive coal seams of the coalfield, having thicknesses of 30 m, 24–30 m and 12 m respectively, yet very little information is available regarding the petrological characters of these coals. It was therefore considered desirable to undertake a detailed study of these coals in this direction. The present paper on reflectance constitutes the first part; the studies on petrographical and chemical characters, which are also complete, form the remaining parts and shall be published shortly.

The reflectance measurements were made on a randomly selected set of 25 samples of which 13 belong to the Kargali seam, 7 to the Karo seam and 5 to the Kuju seam. These samples were collected from different collieries and horizons as listed in Table II.

Experimental Procedure

The apparatus used in the present investigation was a Berek photometer fitted to a Leitz MOP microscope. As suggested by Seyler, measurements were carried out using a Leitz green filter which gives an approximately monochromatic light. All determinations were made at a low intensity which gives accurate results. The adjustable slit of the photometer and the iris diaphragm of the vertical illuminator were closed down as far as possible so that the light falling on the specimen formed the narrowest possible cone. Excepting the primary calibrations of standards, all measurements were made with an oil immersion objective of 1/10 in. using a periplanitic eyepiece of $\times 8$

magnification. In this way an over-all magnification of 540 was obtained. The immersion oil used was the cedar oil of refractive index 1·515.

In order to standardize the instrument, the reflectance of sphalerite (supplied by Leitz) was rechecked according to the formula:

$$R_a = \left(\frac{\sin\theta \text{ sphalerite}}{\sin\theta \text{ quartz}}\right)^2 \times 4{\cdot}614$$

where θ sphalerite and θ quartz are the angular settings of the analyser for sphalerite and quartz. The reflectance of quartz in air is taken as 4·614. The results are shown in Table I from which it is clear that the average observed value of reflectance of sphalerite in air (17·00) is in close agreement with the standard value (16·97).

In the present study sphalerite was used as the standard mineral for measuring reflectance of coal components in oil according to the formula:

$$R_0 = \left(\frac{\sin\theta \text{ coal}}{\sin\theta \text{ sphalerite}}\right)^2 \times 5{\cdot}108$$

where R_0 is the reflectance in oil.

TABLE I

The reflectance measurements of sphalerite in air

Number of observations	R_a per cent
1	17·02
2	16·99
3	16·98
4	17·11
5	17·00
6	17·03
7	19·99
8	17·02
9	17·01
10	16·92
Average	17·00

The coal samples were cut into cubes of about 1 in. and polished along the bedding plane as follows:

(1) Preliminary grinding was carried on by successively finer grades (80, 220, 400, 600, 800) of carborundum powder.

(2) Dry polishing was completed on a polishing machine using emery paper of 1/0, 2/0, 3/0, 4/0 grades.

(3) Wet polishing was completed on a thick compressed felt using levigated Goddard's plate powder as the polishing medium.

(4) Hand polishing was carried on chamois leather.

Results and Discussion

Rank variation

About 50 to 70 readings were made on each sample and six to ten settings were made for each reading. Table II shows the 'maximum' and 'minimum' reflectance (R_0) for 25 samples examined. The reflectance percentages are the average values based on measurements made at a number of places. The values of fixed carbon for all the samples and of carbon for 7 samples, on dry-ash-free basis, are also recorded in the table.

A noteworthy feature is that, while the 'minimum' reflectance for Kargali coals is generally 0·92 per cent, it is about 1·25 per cent for the Karo coals and 0·54 to 0·67 per cent for coals of the Kuju seam. It is also evident from the table that an increase in the reflectance is generally accompanied by an increase in the respective fixed carbon and carbon percentages. Thus, the Kuju coals which show lower reflectance (0·54 to 0·67 per cent) are characterized by lower carbon and fixed carbon (C: 82·46 to 83·17 per cent; FC: 61·9 to 64·6 per cent) while the Karo coals having a higher reflectance (1·25 per cent) show a higher percentage of carbon and fixed carbon (C: 89·96 to 90·02 per cent; FC: 68·9 to 78·8 per cent) and the Kargali coals occupy the intermediate position (R_0: 0·92 per cent; C: 87·38 to 89·76 per cent; FC: 63·6 to 67·2 per cent). Seyler (1943) and Siever (1957) observed a similar relationship between rank and reflectance but each arrived at a different conclusion. Seyler (1943) believed that reflectance remains constant as the carbon increases up to certain critical values when it changes suddenly. Siever (1957), however, observed a more or less continuous variation in reflectance with rank. In Fig. 1, although the graph depicts direct relationship between reflectance (R_0) and fixed carbon, the tendency is more towards 'grouping' than of continuous variation.

There is no systematic variation in the values of 'maximum' reflectance which vary from 1·26 to 3·19 per cent.

Variation in Reflectance

Although Seyler (1943), Sherlock (1951), Mukherjee (1952), Huntjens and Van Krevelen (1954) and Wege (1954) have observed a stepwise variation in reflectance, it has not been found so by Dahme and Mackowski (1950), McCartney (1952), Broadbent and Shaw (1955) and Siever (1957) who are of the opinion that the variation is more or less continuous. In order to study the manner in which reflectance varies in the Bokaro coals, 12 samples (7 from the Kargali, 3 from the Karo and 2 from the Kuju seams) were examined

TABLE II

Reflectance measurements in oil and partial chemical analyses of coal samples

S. No.	Sample number	R_0 per cent 'minimum'	R_0 per cent 'maximum'	Fixed carbon per cent (dry-ash-free)	Carbon per cent (dry-ash-free)	Horizon from top (in metres)
		KARGALI SEAM				
1	S/7, Swang Colliery	0·93	2·35	64·1	87·38	10·5
2	S/9, ,, ,,	0·92	3·13	65·7	—	6·0
3	KB7/3, Bokaro Colliery, Quarry No. 7	0·90	2·25	65·4	—	—
4	KB7/9, ,, ,, ,, ,,	0·92	3·19	66·7	—	3·0
5	KB7/21, ,, ,, ,, ,,	0·91	1·78	66·3	—	6·2
6	KB7/31, ,, ,, ,, ,,	0·92	1·53	66·1	—	8·3
7	KB7/75, ,, ,, ,, ,,	0·92	3·31	67·2	89·46	16·3
8	KB7/76, ,, ,, ,, ,,	0·92	3·15	67·6	—	16·8
9	KB7/84, ,, ,, ,, ,,	0·92	2·26	67·1	—	18·00
10	KB7/96, ,, ,, ,, ,,	0·93	1·76	63·6	—	22·3
11	KB7/102, ,, ,, ,, ,,	0·91	1·67	63·6	—	24·3
12	KB7/109, ,, ,, ,, ,,	0·92	2·79	67·1	89·76	27·0
13	KK3/1, Kargali Colliery, Quarry No. 3	0·92	2·25	65·4		Top
		KARO SEAM				
14	KA/2, Karo Plot 'A'	1·25	3·11	78·6	—	0·6
15	DKB/2, Khas Dhori, Quarry No. 4	1·23	3·10	47·1	—	5·0
16	DKB/7, ,, ,, ,, ,,	0·93	2·26	76·7	89·96	16·5
17	DKT/5, ,, ,, ,, No. 3	1·26	2·88	71·2	—	6·6
18	PKT/5, Pichri Colliery	1·93	2·24	68·9	—	9·0
19	T/1, Turio Colliery	1·18	2·27	70·8	—	Top
20	KSK/2, Kalyani Selected Kargali	1·26	3·14	78·8	90·02	2·5
		KUJU SEAM				
21	WB/K3, Kuju Colliery	0·66	2·73	64·6	—	4·0
22	WB/K4, ,, ,,	0·55	1·65	62·1	83·17	6·0
23	WB/M3, Morpa Colliery	0·54	1·26	61·9	82·46	2·5
24	WB/M4, ,, ,,	0·67	2·46	61·9	—	3·5
25	WB/H3, Haisagarha Colliery	0·65	1·48	62·2	—	2·5

in detail. The observations were made on all constituents except the resinites, sporinites and cutinites. The results are recorded in Table III. The first column gives the reflectance in air of a standard sample of sphalerite. Seyler's standard components, their mean reflectance and the mean percentage deviation are also noted in the table. The deviation per cent may be defined as the difference between the observed values of reflectance and that of the nearest Seyler component expressed as a percentage of the difference between the two components between which the observed value lies. Several reflectance values which do not correspond to Seyler's components but lie close to these have been shown in the respective columns and are marked with an asterisk (*). In the table only average values have been recorded for different

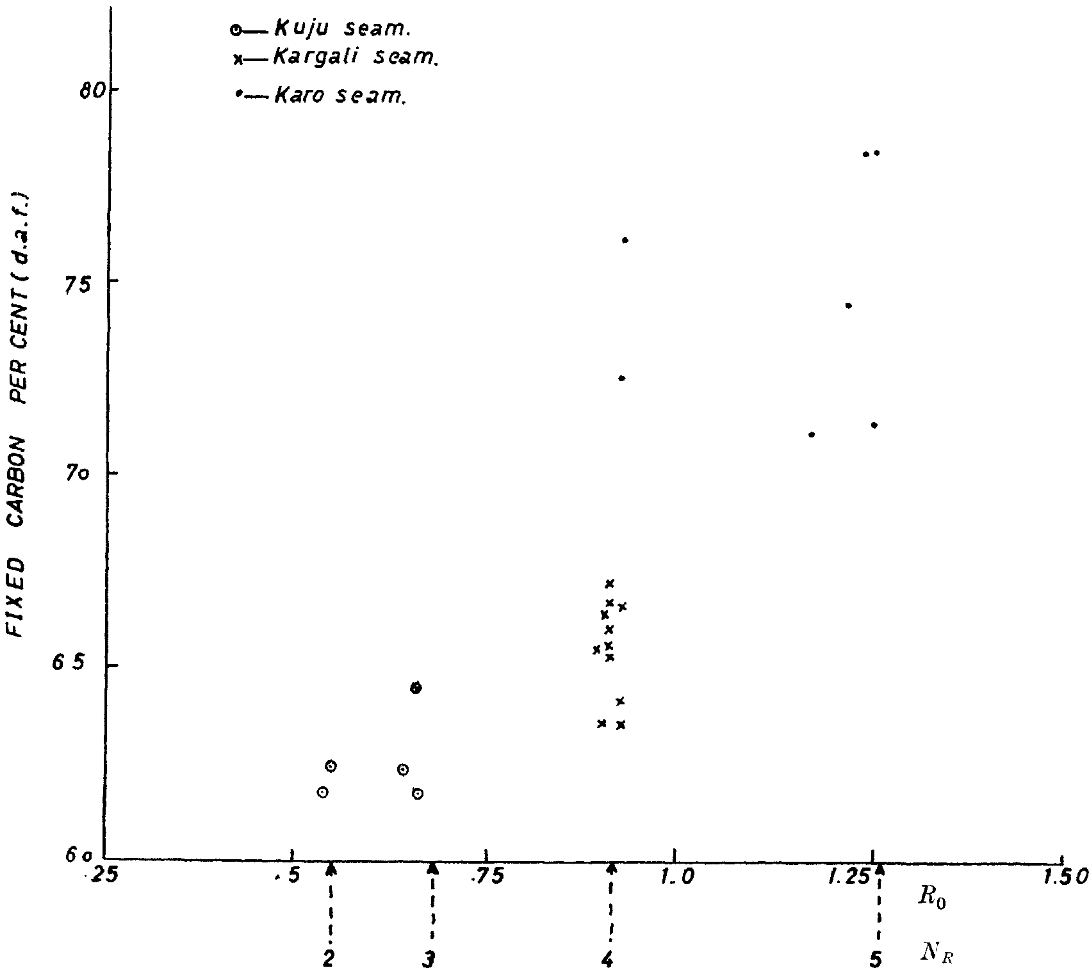


FIG. 1. Fixed carbon and average reflectance (R_0) relationship in coals of the Karo, Kargali and Kuju seams.

TABLE III

Average reflectances in oil for the Kargali, Karo and Kuju coals

Sample number	Reflectance of sphalerite in air (R_0) (per cent)	Component number															
		2	(2b)*	3	(3b)*	4	(4b)*	(5a)*	5	(6a)*	6	(6b)*	(7a)*	7	(7b)*	(8a)*	8
							KARGALI SEAM										
S/7 .. .. (Average of 77 readings)	16·99	—	—	—	—	0·93	—	1·13	1·26	—	1·66	1·85	—	2·25	2·35	—	—
KB7/9 .. .. (Average of 71 readings)	—	—	—	—	—	0·93	—	—	1·25	—	1·67	—	2·00	2·25	—	2·89	—
KB7/31 .. .. (Average of 55 readings)	16·98	—	—	—	—	0·92	—	1·18	1·25	1·64	—	—	—	—	—	—	—
KB7/75 .. .. (Average of 70 readings)	—	—	—	—	—	0·92	1·06	—	1·23	—	1·62	1·83	2·04	2·21	—	—	3·11
KB7/76 .. .. (Average of 60 readings)	17·01	—	—	—	—	0·93	1·03	—	1·25	1·47	1·65	—	1·95	2·21	—	—	3·14
KB7/96 .. .. (Average of 58 readings)	—	—	—	—	—	0·93	—	—	1·25	1·47	1·62	1·77	—	—	—	—	—
KB7/102 .. .. (Average of 49 readings)	17·00	—	—	—	—	0·92	1·05	—	1·23	1·46	1·65	—	—	—	—	—	—
							KARO SEAM										
KA/2 .. .. (Average of 64 readings)	17·04	—	—	—	—	—	—	—	1·25	1·47	1·65	—	1·99	2·25	—	2·72	3·12
PKT/5 .. .. (Average of 54 readings)	—	—	—	—	—	—	—	—	1·26	1·46	1·64	—	1·96	2·24	—	—	—
T/1 .. .. (Average of 49 readings)	—	—	—	—	—	—	—	1·17	1·27	—	1·65	—	1·97	2·25	—	—	—
							KUJU SEAM										
WB/M3 .. .. (Average of 51 readings)	17·03	—	—	0·64	0·75	0·93	1·11	—	1·24	—	—	—	—	—	—	—	—
WB/K4 .. .. (Average of 62 readings)	—	—	0·58	0·66	0·76	0·90	—	—	1·27	1·47	1·65	—	—	—	—	—	—
Mean value	17·00			0·65		0·92			1·25		1·64			2·24			3·12
Seyler's figures				0·67		0·92			1·26		1·64			2·23			3·11
Deviation per cent				2·25		0·00			2·29		0·00			1·69			2·25

* Components which do not correspond with those of Seyler but lie close to them.

components, while the total number of readings on which the average values are based is given below the sample number within parentheses. The results of reflectance measurements of the Kargali, Karo and Kuju seams are represented as bar diagrams in Figs. 2 to 5 which bring out the variation in a clear way.

There is a definite tendency for reflectance values to cluster round certain discrete peaks, the number of which usually vary from 4 to 8. The deviation per cent generally is between 2 and 3 which shows that in the majority of cases the scattering round the respective means is not pronounced and this is evident from the bar diagrams also. A notable feature is that, while the majority of peaks have their mean reflectance values remarkably identical with those given by Seyler to his discrete components, there are others—the secondary peaks—which form distinct groupings in between the primary peaks.

Though the number of the primary peaks or Seyler's standard components is almost the same in all the coals, the manner of their distribution is quite distinctive in the three seams. Thus, while No. 4 component is prevalent in the Kargali coals, No. 5 is dominant in the Karo coals and No. 3 prevails in the Kuju coals.

The secondary peaks are so conspicuous and persistent that their presence cannot be ignored. These have also been noted by Huntjens and Van Krevelen (1954), who believe that 'the spread in results of reflectance measurements on a given vitrinite may be due to: (*a*) variability of the refractive index, which may be caused by infiltration of "resinite" into the vitrinite, or by anisotropic effects; (*b*) an increase in the absorptive index, owing to diffusion of light'. An observer (F) working with Seyler (1952) has also noted several secondary peaks but no explanation has been offered for the scattering.

An interesting point about the secondary peaks is that these are prominent between lower components, viz. Nos. 4 to 7, which evidently represent the vitrinite and first few intermediates. The vitrinite-forming tissues have been often observed impregnated with peaty solutions which substantially affect their translucency and thereby mask or exaggerate their power of reflection. The reflectance values so obtained are different and do not represent the vitrinites truly. The result is that various irregularly spaced subsidiary or secondary peaks are observed.

An over-all examination of the distribution of reflectance, however, shows that, while the evidence is largely in favour of Seyler's grouping hypothesis, there are a few cases as shown in Figs. 2(*a*), 2(*d*), 3(*e*), 4(*a*) and 5(*b*) in which secondary peaks are more closely spaced. It is difficult to say exactly whether the variation in reflectance is stepwise or more or less continuous in these cases. In a delicate problem of reflectance measurements, the comparison of results is based entirely on human judgement which is not a precise criterion. A satisfactory solution of the problem may be obtained if an appropriate statistical test is applied to the given data.

KARGALI SEAM

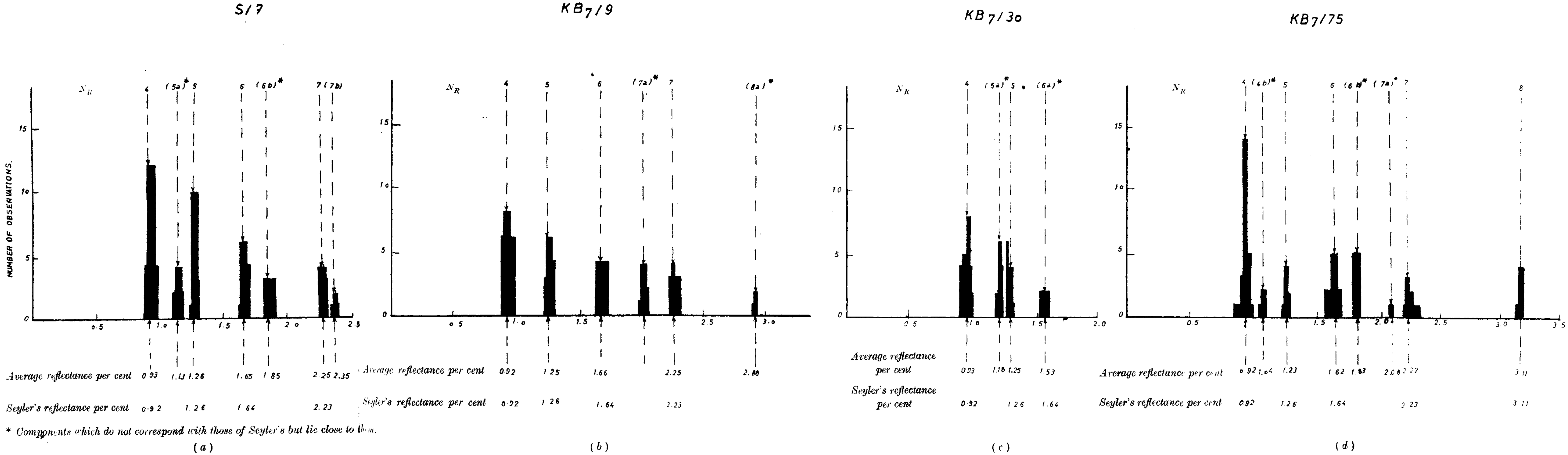


FIG. 2. Reflectance (R_0) variation in some coals of the Kargali seam from Swang and Bokaro collieries.

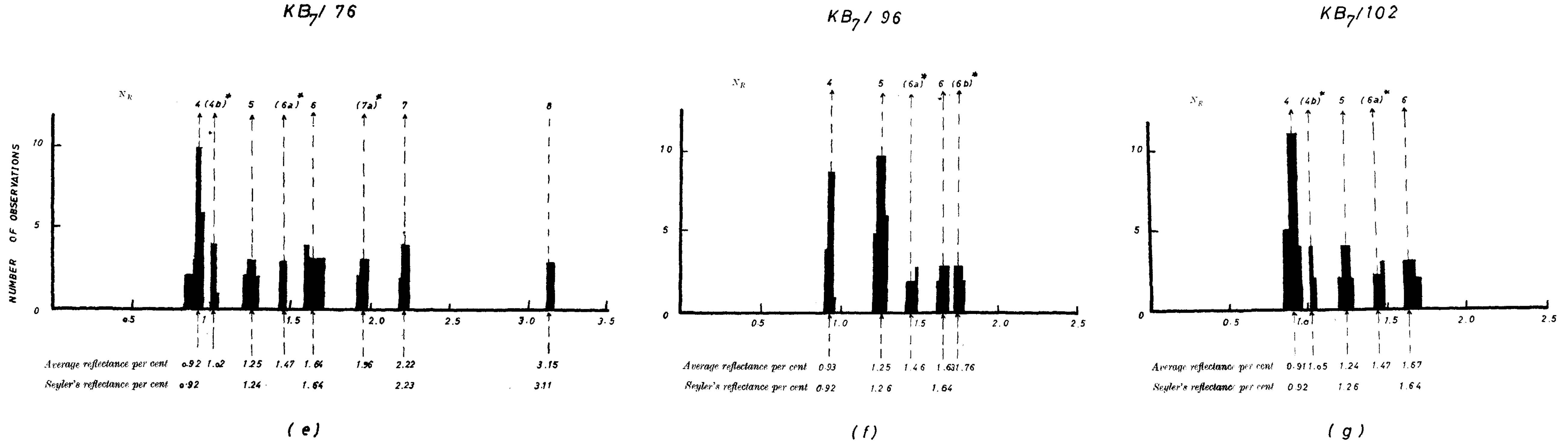


Fig. 3. Reflectance (R_0) variation in some coals of the Kargali seam.

Lumped Variance Test for Grouping

Broadbent and Shaw (1955) applied for the first time 'lumped variance test' to the study of coal reflectance. This test helps to find out if the given reflectance values have a tendency to cluster round certain peaks.

The mathematical model proposed by Seyler for reflectance data is:

$$R = \beta + 2\delta N_R + \epsilon$$

where R denotes the logarithm of the measurement of reflectance in oil, 2δ are constants with values log 0·26 and log 1·36 respectively, N_R is an integer between 0 and 9 and ϵ is the error of measurement. The lumped variance test is designated by the formula:

$$S^2 = \sum_{i=1}^{n} Z_i^2/n$$

where n refers to the number of observations made and Z_i corresponds to the ith observation. S^2 is therefore the average squared distance of the data from the peaks indicating whether the values tend to cluster round the peaks. The value is zero if observations are precisely at the peak, low if they cluster closely, and high if they do not cluster.

As an alternative to the Seyler's model, Broadbent and Shaw (1955) proposed the rectangular hypothesis according to which there is a smooth distribution of S^2 values with no evidence of clustering at the peaks. It was further suggested that if the variance of error (ϵ) increases, even though there is stepwise variation, S^2/δ^2 will increase and there will be a smooth distribution of S^2 values.

According to this test if S^2/δ^2 is not significantly different from 1/3, the model is rejected, i.e. the data are compatible with rectangular hypothesis. If S^2/δ^2 is significantly smaller than 1/3, the model is accepted. The critical values of S^2/δ^2 at the 5 per cent and 1 per cent levels of significance, as given by Broadbent (1955), are listed below:

Number of observations	Significance level	
	5%	1%
20	0·114	0·178
25	0·235	0·194
35	0·250	0·216
40	0·256	0·244
45	0·260	0·229
55	0·267	0·239
60	0·270	0·244
65	0·272	0·247
75	0·276	0·263
80	0·279	0·256

The lumped variance test was applied to the data average of which is shown in Table III. The results are recorded in Table IV where 5 per cent level of significance is used in order to determine whether or not the Seyler's model is acceptable.

TABLE IV

Results of variance test for grouping

S. No.	Sample number	Number of observations	S^2/δ^2	Conclusion, model is
1	S/7	77	0·103	Accepted
2	KB7/9	71	0·150	,,
3	KB7/31	55	0·182	,,
4	KB7/75	70	0·194	,,
5	KB7/76	60	0·153	,,
6	KB7/96	58	0·183	,,
7	KB7/102	49	0·184	,,
8	KA/2	64	0·184	,,
9	PKT/5	54	0·142	,,
10	T/1	49	0·188	,,
11	WB/M3	51	0·179	,,
12	WB/K4	62	0·181	,,

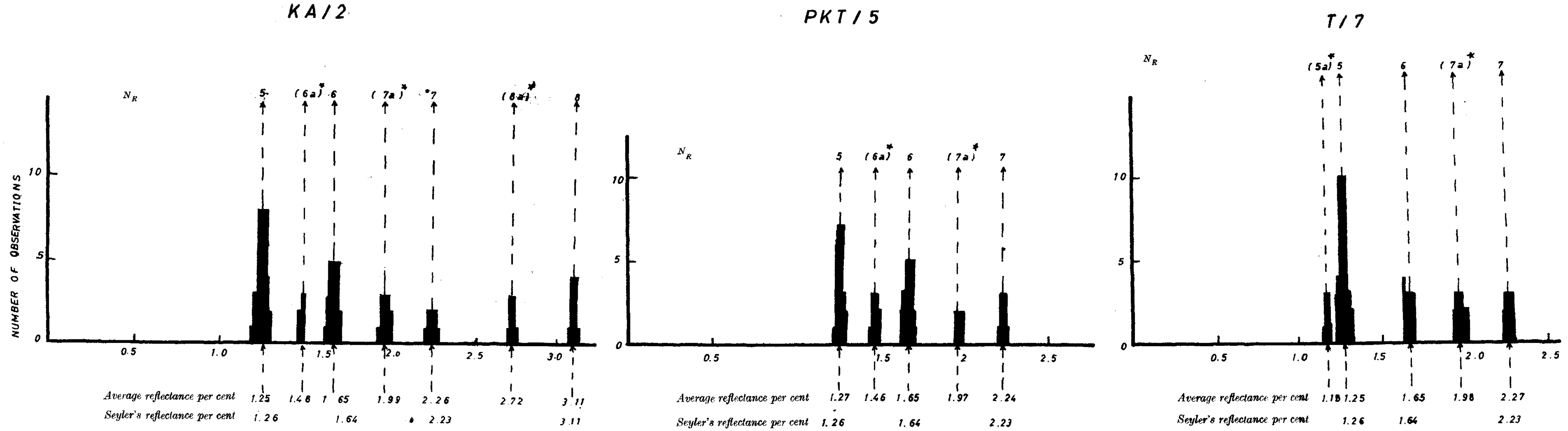
From the table it is evident that S^2/δ^2 for each sample is significantly less than 1/3 suggesting that Seyler's model holds good. Even in the few cases shown in Figs. 2(*a*), 2(*d*), 3(*e*), 4(*a*) and 5(*b*), where visual judgement shows some doubt about the validity of grouping hypothesis, S^2/δ^2 is significantly less (0.103, 0·194, 0·153, 0·184 and 0·181), confirming thereby that the data are incompatible with rectangular hypothesis and follow the Seyler's model.

Petrological Analysis and Somatic Variation

The vitrinite and opaque constituents, like fusinite, semifusinite and micrinite, are the two main attributes which determine whether a coal is bright or dull. The reflectance studies have shown that a coal is comprised of a set of petrological components each of which has a varying frequency depending upon the rank and type of coal.

In order to study the frequency distribution or the somatic variation of the various components and to find out the variation in reflectance with change of rank, six samples, two each from the Kuju, Kargali and Karo seams, were selected for quantitative petrological analysis using Dollar's integrating stage. The results of the analysis are recorded in Table V and histograms showing frequency variation are shown in Fig. 6. The component having the minimum reflectance generally shows peakedness in the bright coals as it represents vitrinite. With the increase in rank the next higher component

KARO SEAM


KA/2
PKT/5
T/7
NUMBER OF OBSERVATIONS
N_R
5 (6a)* 6 (7a)* 7 (8a)* 8
5 (6a)* 6 (7a)* 7
(5a)* 5 6 (7a)* 7
Average reflectance per cent 1.25 1.46 1.65 1.99 2.26 2.72 3.11
Seyler's reflectance per cent 1.26 1.64 2.23 3.11
Average reflectance per cent 1.27 1.46 1.65 1.97 2.24
Seyler's reflectance per cent 1.26 1.64 2.23
Average reflectance per cent 1.18 1.25 1.65 1.98 2.27
Seyler's reflectance per cent 1.26 1.64 2.23

KUJU SEAM

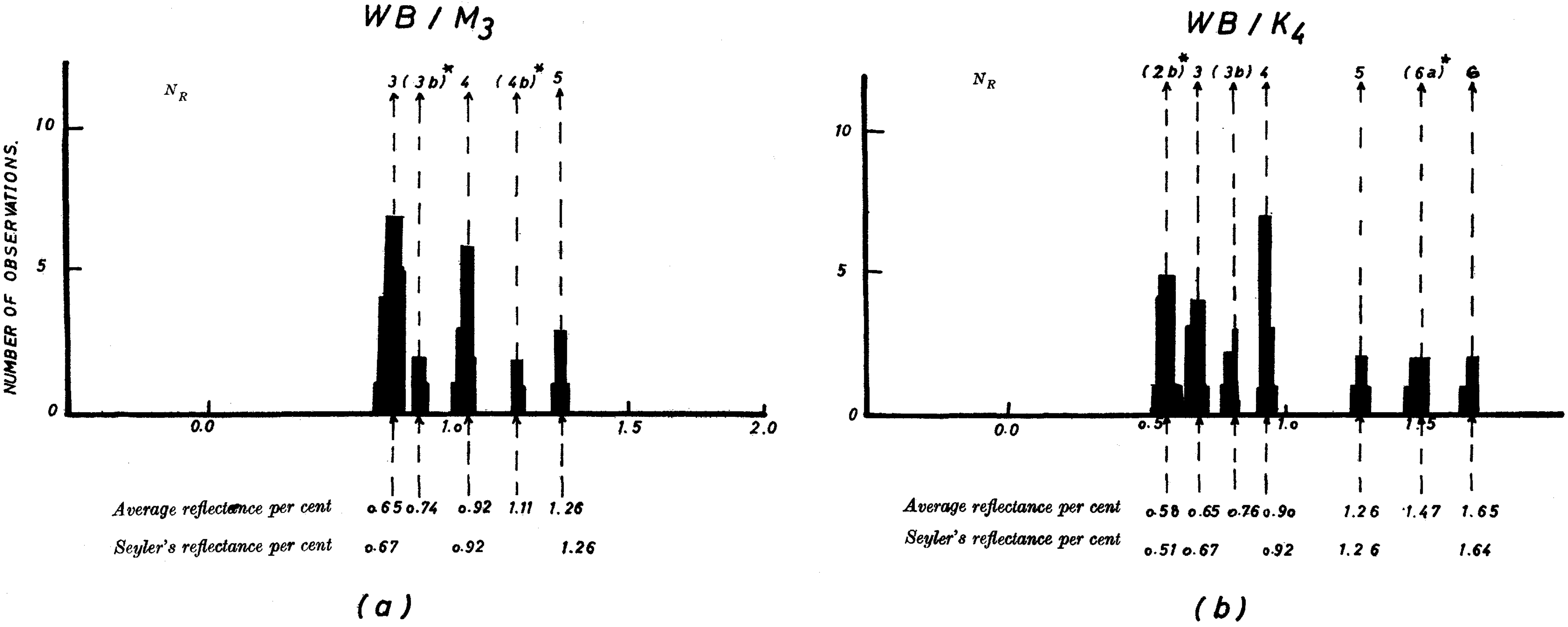


FIG. 5. Reflectance (R_0) variation in some coals of the Kuju seam.

shows peakedness. Thus in order of increasing rank in coals of the Kuju, Kargali and Karo seams peakedness is shown by Nos. 3, 4 and 5 components respectively. In the durainy coals, however, where intermediates acquire prominence, peakedness is not so well marked and the first two or three components generally constitute the bulk of the coal. Thus on the basis of

TABLE V

Reflectance percentage of some typical coals

Sample number and type of coal	Reflectance R_0 (per cent)	N_R	Description of component	Per cent (by volume)	Calculated per cent of standard component (by volume)
WB/M3—*Kuju Seam*					
Vitrainy (bright) coal	0·65	3	Vitrinite	78·3	81·9
	0·74	(3b)*		2·3	
	0·92	4	1st Intermediate	12·8	13·4
	1·11	(4b)*		2·1	
	1·26	5	2nd ,,	4·5	4·7
					100·0
WB/K4—*Kuju Seam*					
Durainy coal	0·57	(2b)*		2·7	
	0·65	3	Vitrinite	30·8	33·9
	0·76	(3b)*		4·5	
	0·90	4	1st Intermediate	42·1	46·5
	1·26	5	2nd ,,	5·0	5·6
	1·47	(6a)*		2·2	
	1·65	6	3rd ,,	12·7	14·0
					100·0
KB7/75—*Kargali Seam*					
Vitrainy (bright) coal	0·92	4	Vitrinite	76·5	83·8
	1·07	(4b)*		3·5	
	1·23	5	1st Intermediate	5·3	5·9
	1·62	6	2nd ,,	4·8	5·5
	1·83	(6b)*		2·9	
	2·08	(7a)*		2·8	
	2·24	7	3rd ,,	3·1	3·5
	3·10	8	4th ,,	1·1	1·3
					100·0

* Components which do not correspond with those of Seyler but lie close to them.

TABLE V—(*concld.*)

Sample number and type of coal	Reflectance R_0 (per cent)	N_R	Description of component	Per cent (by volume)	Calculated per cent of standard component (by volume)
KB7/96—*Kargali Seam*					
Durainy coal	0·93	4	Vitrinite	39·4	41·9
	1·25	5	1st Intermediate	42·8	45·6
	1·46	(6a)*		1·6	
	1·63	6	2nd ,,	11·7	12·5
	1·76	(6b)*			
					100·0
PKT/5—*Karo Seam*					
Vitrainy (bright) coal	1·27	5	Vitrinite	27·1	79·2
	1·46	(6a)*		3·6	
	1·65	6	1st Intermediate	11·4	12·5
	1·97	(7a)*		5·3	
	2·24	7	2nd ,,	7·6	8·3
					100·0
KA/2—*Karo Seam*					
Durainy coal	1·25	5	Vitrinite	55·7	59·3
	1·48	(6a)*		2·2	
	1·65	6	1st Intermediate	32·4	34·8
	1·99	(7a)*		3·1	
	2·26	7	2nd ,,	3·1	3·4
	2·72	(8a)*		1·2	
	3·11	8	3rd ,,	2·3	2·5
					100·0

* Components which do not correspond with those of Seyler but lie close to them.

frequency distribution of petrological components, or somatic pattern, the rank of a coal can be easily ascertained.

In spite of the best efforts it could not be possible to differentiate exactly between the various opaque constituents especially the semifusinite and fusinite and, therefore, these are designated as 'Intermediates'. Siever (1957), however, has been able to differentiate between micrinite, semifusinite and fusinite and has given a range of reflectance for each. His values, however, overlap and it is doubtful if these can be of any practical utility.

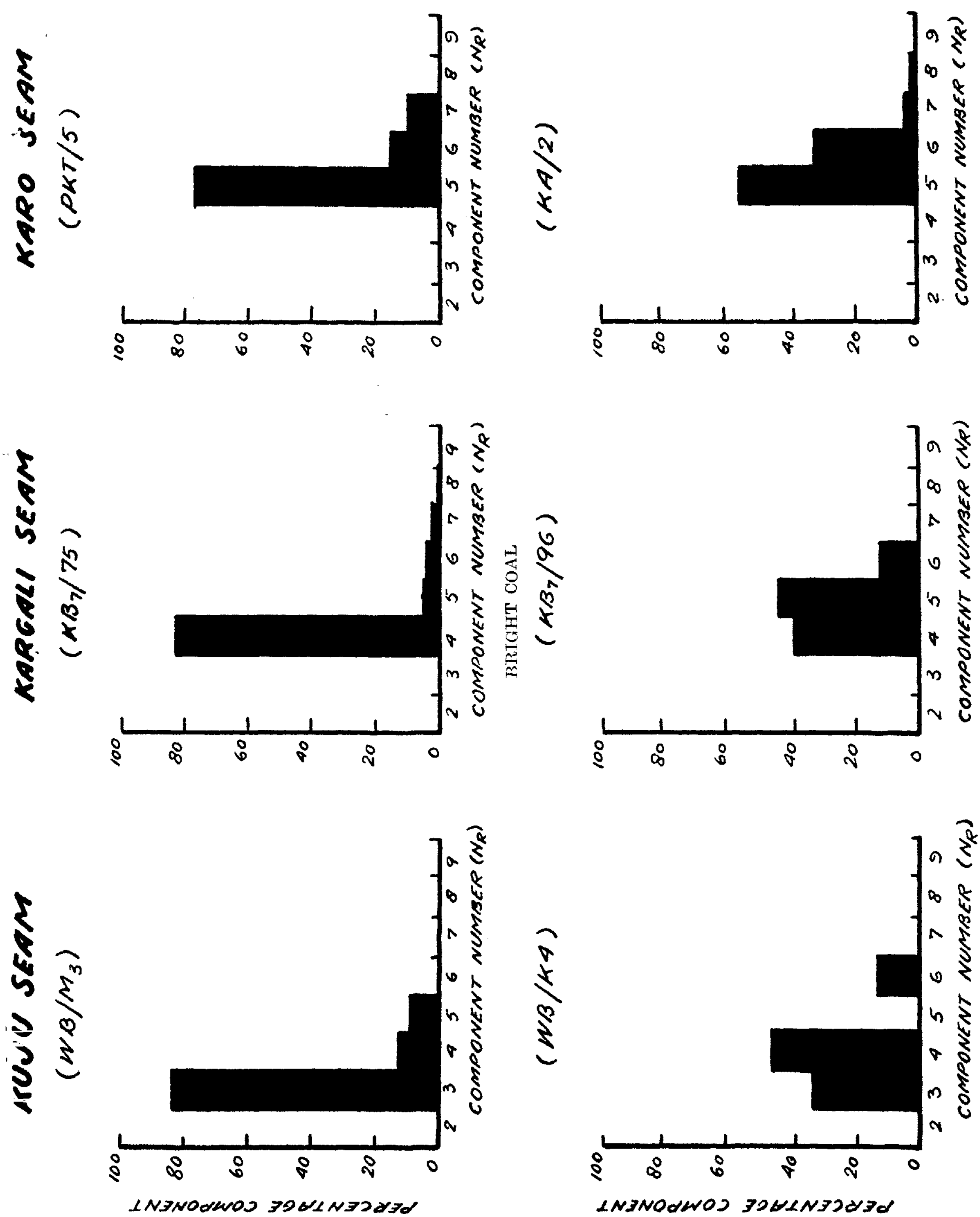


FIG. 6. Frequency distribution of components (N_R) in some typical 'BRIGHT' and 'DULL' coals of the Kuju, Kargali and Karo seams.

Summary and Conclusions

As no systematic work on the reflectivity of Indian coals has been done so far, it was considered desirable to undertake such a study on the Bokaro coals. The choice of the Bokaro coalfield was influenced particularly by the fact that, although it is one of the important coalfields of India, very little information is available regarding the petrological character of these coals. The Barakars of the Lower Gondwanas occupy a greater part of the field and are the chief coal-bearing strata. Out of the eight productive coal seams occurring in this coalfield, three seams, namely the Kargali (30 m), Karo (24–30 m) and Kuju (12 m), are more important and have been chosen for this investigation.

The present study which is based on 25 randomly selected samples has twofold objects: to establish the rank of these coals and to observe the manner of reflectance variation.

It is evident from the chemical data given in Table II that, while the Kuju coals are characterized by lower carbon and fixed carbon (C: 82·46–83·17 per cent; FC: 61·9–64·6 per cent), the Karo coals show a higher percentage of carbon and fixed carbon (C: 89·96–90·02 per cent; FC: 68·9–78·8 per cent) and the Kargali coals occupy the intermediate position (C: 87·38–89·76 per cent; FC: 63·6–67·2 per cent). According to the I.S.I Classification (General Classification of Coals: Indian Standard Institution, 1955, No. 770), although most of these coals belong to the bituminous rank, there is a distinct variation in the degree of maturity as is evident by the wide range of carbon. Thus, while the Kuju coals belong to the B_4 group of the I.S.I Classification, the Kargali and Karo coals belong to B_3 and B_2 groups respectively. Reflectivity values (R_0), which are markedly different for each seam (average R_0 : Kuju, 0·67 per cent; Kargali, 0·92 per cent; Karo, 1·25 per cent), further confirm such a variation in the rank. Seyler and Chandra (1955) have correlated reflectance values with rank and in the light of this correlation it may well be suggested that, while the Kuju coals are meta-lignite, the Kargali and Karo coals are para- and ortho-bituminous respectively.

As regards the manner of reflectance variation there is a definite evidence of reflectance values (R_0) to cluster round certain regularly spaced peaks which are in close conformity with those observed by Seyler. Several secondary peaks, particularly between component Nos. 4 and 7, have also been observed. The validity of grouping hypothesis is further confirmed by the lumped variance test. The somatic pattern in some typical 'bright' and 'dull' coals has been studied. While the component (N_R) of minimum reflectance constitutes the bulk of the bright coals, the first two or three components acquire prominence in the dull coals.

Studies in the reflectivity of coal have a fertile field for research in this country as no significant contributions on these lines have been made till now. It will indeed be in the interest of the subject if, instead of wasting time in solving the long-standing controversial problem of reflectance variation, some serious attempts are made to explore methods by which reflectivity can find useful application in problems of practical utility, viz. the carbonization of coal, classification of coal and the rank of coal, etc. It is now being generally recognized that reflectance can play an important role in the classification of coals. Such a classification, according to Siever (1957, p. 9), will be 'rapidly and easily performed and also should have the advantage of being based on non-empirical analyses of one of the fundamental physical properties of the homogeneous petrographic components that make up the coal substance'.

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References

Broadbent, S. R. (1955). Quantum Hypothesis. *Biometrika*, **42**, 53.

Broadbent, S. R., and Shaw, A. J. (1955). Reflectance of coal. *Fuel*, **34**, 385–403.

Dahme, A., and Mackowski, M. T. (1950). Physico-chemical and petrographic investigations of coal, coke and graphite. IV. New methods of determination of the reflectivity of coal. *Brennstoff-chemie*, **31**, Heft Nr. 9/10, 129–138.

Hoffman, E., and Jenker, A. (1933). Coalfication and its detection under the microscope. *Fuel*, **12**, 98–106.

Huntjens, F. J., and Van Krevelen, D. W. (1954). Chemical structure and properties of coal. II. Reflectance. *Fuel*, **33**, 88–103.

McCartney, J. T. (1952). A study of the Seyler theory of coal reflectance. *Econ. Geol.*, **47**, 202–210.

Mukherjee, B. C. (1952). Studies of the reflectance of coal of some forms of carbon for vertically incident light. *Fuel*, **31**, 153–158.

———— (1961). Studies on chemical, petrological, reflectivity and electrical conductivity characters. XIV. Seam coal, affected by igneous intrusive, from Keshargara Colliery, Dhanbad district, Bihar. *Proc. 48th Indian Sci. Cong.*, III, 201-202.

Seyler, C. A. (1943). Recent progress in the petrology of coal. *J. Inst. Fuel.*, **16**, 134–141.

———— (1952). Characteristic petrological components of coal. *Fuel*, **31**, 159–170.

Seyler, C. A., and Chandra, D. (1955). Discussion of 'Reflectance of Coal' by S. R. Broadbent and A. J. Shaw. *Fuel*, **34**, 503–513.

Sherlock, E. (1951). Studies on some properties of Alberta coals. III. Reflectivity and fine structure. *Fuel*, **30**, 75–78.

Siever, R. (1957). Variation in coal reflectance. *Ill. State geol. Surv. circular*, 241.

Stach, E. (1949). Lehrbunch der kohlenmikroskopie. Verlag Glückauf, Essen, **1**, 285.

Wege, E. (1954). Chemische-physikalische und petrographische Untersuchungen an Kohlen, Koksen und Graphiten. VI. Untersuchungen uber das Reflexion Vermogen und die Reflexions anisotropie von Vitriniten: *Brennstoff-chemie*, **35**, Heft Nr. 1/2, 1–6, 33–41.