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# BRANDSTOFNAVORSINGSINSTITUUT
## VAN SUID-AFRIKA

# FUEL RESEARCH INSTITUTE
## OF SOUTH AFRICA

ONDERWERP:
SUBJECT: THE PRACTICE OF COAL PETROGRAPHY IN SOUTH AFRICA

AFDELING:
DIVISION: SURVEY

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# FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

## REPORT NO. 7 OF 1971

## THE PRACTICE OF COAL PETROGRAPHY IN SOUTH AFRICA.

### INTRODUCTION

The physical, chemical and petrographic properties of South African coals are, in the majority of cases, rather irregular by European standards. This is particularly true in respect of the coking coals.

South African coking coals are not true coking coals. Their maturity was not wholly induced by the influence of the normally accepted agent, namely time-temperature.

The establishment of Hilt's law is difficult considering that all the coal seams in the different coal-fields in the country are in close proximity to each other and seldom exceed 500 feet. Furthermore, dolerites, of which the influence can not always readily be detected, occur in every coal-field to a greater or lesser extent. Lateral changes in rank also occur where no dolerites are present.

The anomalous behaviour of the coals has been described elsewhere[1,2] and will not be discussed in detail but will be referred to in due course.

The causes of the anomalous behaviour can mainly be attributed to the following:

1) High mineral matter content of the coal.
2) The physical and chemical composition of the coal seams.
3) The fairly to extremely high concentration of inert components of which semi-fusinite preponderates.
4) The presence of igneous intrusions and their variable influence on the coal.

### 1.0 THE CHARACTERIZATION OF SOUTH AFRICAN COALS

In order to establish some link between the petrographical characteristics of the coal and their technological application, extensive work was and is still being carried out.

/1.1 .....

## 1.1 Survey of Colliery Products

The survey included all the classes of coal with the exception of the anthracites.

The different size grades produced by 57 major collieries were petrographically analyzed and evaluated over a number of years.

Colliery products differ in composition with size grades and seams worked but vitrinite and semi-fusinite are invariably predominant. The ratio in which the two occur in the Natal coals is normally 2:1 and the sum of the two on a visible mineral matter free basis, is just over 90 per cent. None of the other macerals occurs in greater quantities than 4 per cent. In the Transvaal and Orange Free State vitrinite and semi-fusinite constitute 86 to 88 per cent of the coal and the ratios are in the order of 2:1 and 1,5:1, respectively. The minor inert constituents are present to the extent of 5 to 6 per cent, while the exinites are present to the extent of 7 to 8 per cent. There is thus much similarity in the petrographic composition of the coals.

## 1.2 Work on Low Ash vitrinites

In order to eliminate the influence of mineral matter, Savage and Briel[3)], with the co-operation of other departments at the Fuel Research Institute, investigated a number of parameters by working on low ash vitrinite concentrates. The concentrates were analyzed and compared both with overseas coals and data available on normal South African products.

Product samples taken on a routine basis were crushed to 5 mm and the reject portion from sample reduction used to produce the concentrates. The normal procedure was to remove the minus 0,5 mm material and the balance was floated at successively lower specific gravities until a yield of about 5 per cent of the low ash product was obtained. The samples were floated at this fairly coarse size in order to minimize oxidation and the adsorbtion of the flotation medium which consisted of a mixture of carbon tetrachloride and light petroleum ether. Even at this low yield the ash contents and concentration of

/inert .....

inert material were in some cases higher than desirable. Thus, for some low vitrinite coals the samples were obtained by selecting lumps in which vitrain was visibly present prior to the process of concentration described above.

The aim of the investigation was to produce a concentrate of low ash vitrinite and this was, generally speaking, achieved. The ash reduction was in some cases very substantial by South African standards and the ash contents of the products obtained ranged between 1,8 and 7,8 per cent. By comparison, the ash contents of the coals from which the concentrates were derived varied between 8 and 23 per cent. The vitrinite content of the products increased by about 30 per cent and a relatively large number of them contained more than 90 per cent vitrinite.

However, notwithstanding the very low specific gravities used in the separation and other precautions taken, the vitrinites were not completely pure. The exinites varied between 1 and 8 per cent which is normal for the coals. This was rather surprizing because the exinites in South African coals are usually associated with mineral matter and experience has shown that the specific gravity of the exinitic material is slightly higher than that of the vitrinite. Semi-fusinite was substantially reduced and normally varied between 1 and 9 per cent, but in three cases amounts of between 10 and 15 per cent were recorded. The other inert macerals occurred in amounts of about 1 per cent and lower.

It can thus be concluded that the two major effects of concentration are the reduction in mineral matter (i.e. the ash-forming constituents, which means in most cases a reduction in carbonates and pyrites as well as clay minerals) and reduction in inertinite.

Since the content of mineral matter from which the ash is derived is about 1,1 to 1,2 times the ash content, the complications that carbon dioxide is measured as elemental carbon, water of constitution of the clays is measured as hydrogen, and that both of these plus about half the mineral sulphur contribute to the volatile matter content, certain

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departures from the pure coal analysis do occur.

Thus, with analyses of South African coals, dry ash-free carbon is always too low, hydrogen tends to be slightly too high. Nitrogen and sulphur are slightly low while the oxygen is definitely high, as is the volatile matter.

By reducing the ash content of the coal as well as the inertinite content and increasing the vitrinite content, the dry ash-free analytical values of the coals change considerably. It is not the purpose of this paper to go into these changes but suffice to say that the carbon relationship with reference to moisture, swelling number, calorific value, etc. follow the same lines as are found for U.K. coals, with the exception that they fall outside the normal limits for the coals. Certain displacements occur particularly in the case of the low rank coals having a very high inertinite content but in general if some 2 to 3 per cent is added to each carbon plot the properties of the coals will be very similar to those of the U.K. The only relationship that concerns this paper is that between the dry ash-free carbon content and reflectance.

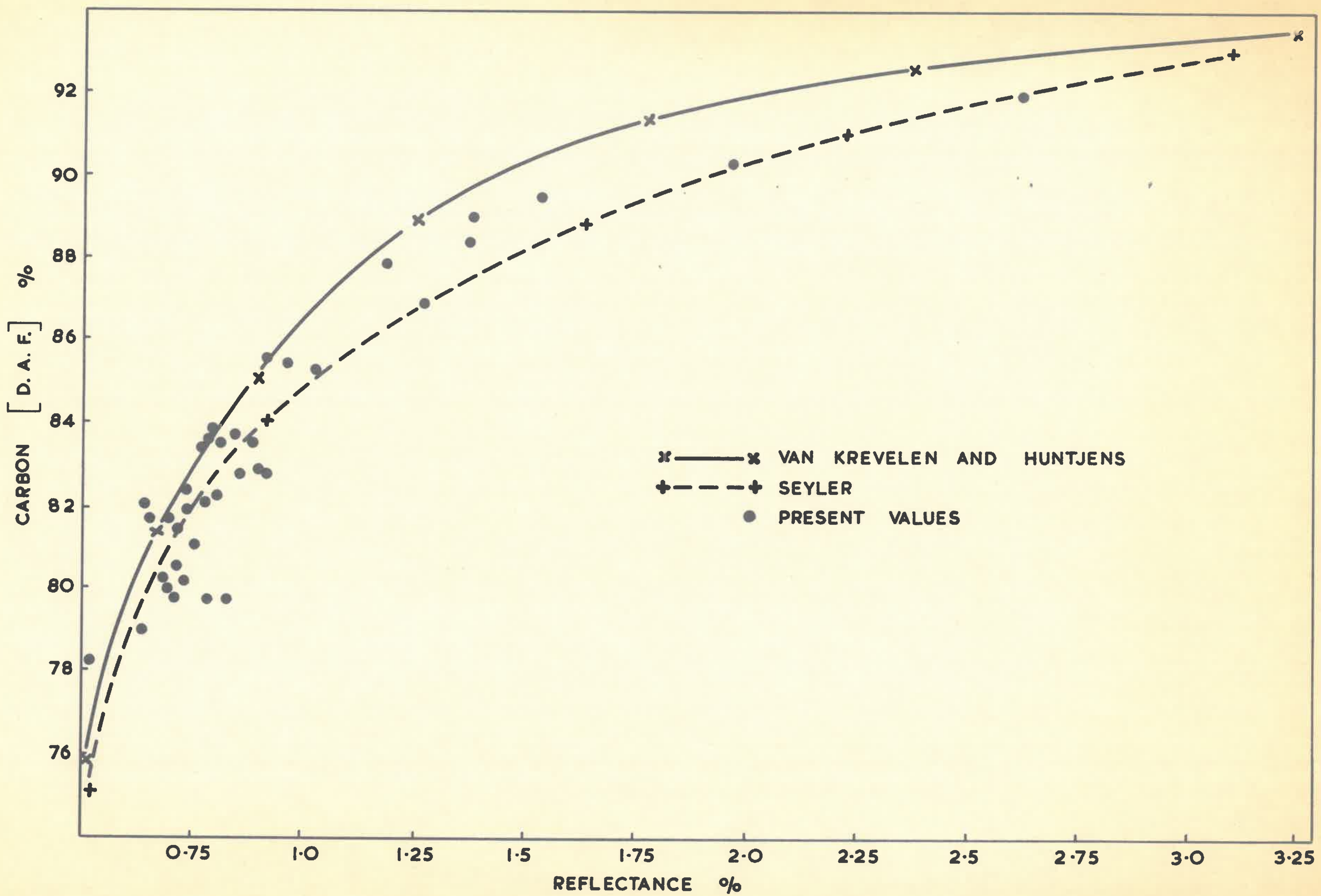
## 1.3 The Relationship Between Dry Ash-free Carbon Content and Reflectance

The relationship between the dry ash-free carbon content of the vitrinites and the mean maximum reflectance is given in Diagram 1. The broken curve has been drawn through points given by Seyler and the other curve according to van Krevelen and Huntjens as given in Francis[4)] on pages 580 and 769, respectively.

The points giving the relationship between the two parameters form a rough band but three coals, one from Natal, one from Ermelo in the Transvaal and one from the Orange Free State have too low a reflectance for their carbon contents. On the other hand four other coals, two from the Orange Free State and two from the Witbank No. 5 Seam have too high a reflectance for their carbon contents. This result is remarkable for one coal in particular, namely, an Orange Free State coal where the high concentration of inertinite would be expected to increase the carbon content significantly compared with that of pure

/vitrinite .....

DIAGRAM I




REFLECTANCE AND COAL RANK

vitrinite.

The shape of the curve suggests that at high rank fairly large changes in reflectance will have little effect on the carbon content. On the other hand, for low rank coals small changes in reflectance suggest large changes in carbon content. Bearing in mind that South African coals sometimes, as a result of the effect of dolerite, show a broad spectrum of reflectance, this latter point is of importance.

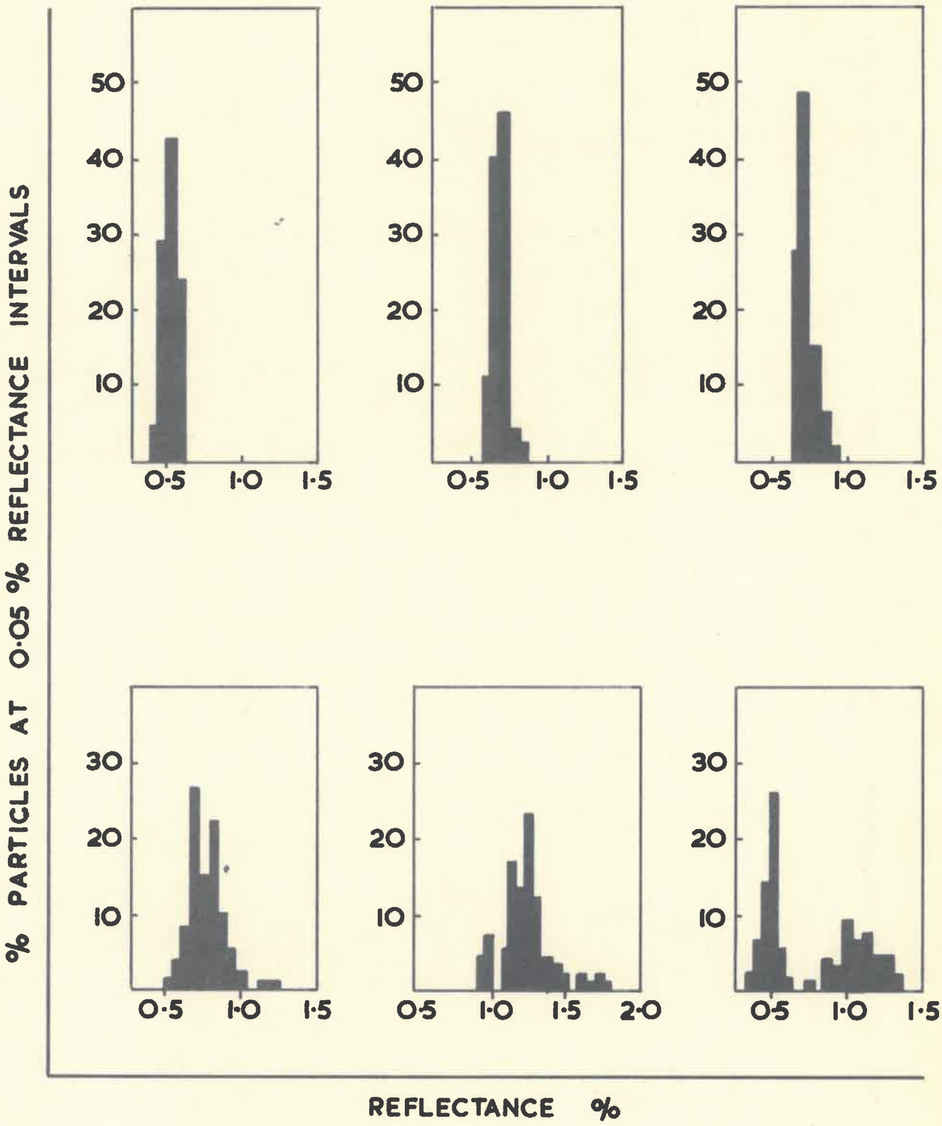
Diagram 2 shows the reflectance histograms of the vitrinites of six of the coals investigated. The top three are of vitrinites which show very narrow spectrums and one must assume that no dolerites were present in the proximity of where the coals were mined, while the bottom three are of vitrinites derived from coal mined in areas where it is known that dolerites are present.

Considering the last histogram in the bottom row, it appears as if the concentrate consists of more or less equal portions of unaffected coal and coal which had been appreciably altered as a result of dolerite intrusions. In assessing the rank of the coal by means of reflectance, one is left with the choice of either assessing the rank from the mean reflectance of the whole sample or estimating the higher and lower rank separately and calculating the rank from the relative proportion of the two components. The two methods would yield different results with the second method yielding the lowest results.

Since the rank of South African coals can not be satisfactorily expressed in terms of dry ash-free volatile matter content and better results can be obtained by expressing it in terms of dry ash-free carbon content, Savage suggests that any relatively low rank coal with a wide reflectance spectrum could be better assessed as regards rank by assigning carbon contents to each step of the histogram or to each individual reading of reflectance and calculating the average carbon content rather than the average reflectance.

In the particular case represented by Histogram No. 6, the chemical analysis gave a dry ash-free value of 79,70 per cent, the value calculated by means of assigning the

DIAGRAM 2




REFLECTANCE HISTOGRAMS OF LOW ASH

VITRINITE CONCENTRATES

carbon content to each step in the histogram as suggested, amounted to 80,8 per cent and that calculated from the average reflectance to 83,0 per cent.

## 1.4 Coking Coals and Swelling Properties

The bituminous coals can be classified as straight coking coals (occurring with one exception all in Natal), blend or weakly coking coals (mainly from the Witbank district of the Transvaal) and non-coking coals.

A most interesting feature about the so-called "non-coking" coals is that a large number of them (including even some of the low rank coals with a dry ash-free carbon content of 79 per cent) contain a low specific gravity fraction which shows swelling properties.

Of the 37 coals investigated by Savage and Briel, three were anthracites, nine straight and blend coking coals and twenty-five so-called "non-coking" coals. Of the latter, no less than thirteen were found to contain low specific gravity swelling coal with B.S. swelling numbers ranging between 9 and 4. Only five coals had no swelling properties at all. As can be expected, the low ash concentrates of the coking coals showed improved swelling numbers. The corresponding product samples gave swelling numbers of 0 to less than 2 for all but a few coals, some of which have been used exclusively for carbonization.

Some of the striking differences in swelling properties, together with differences in the ratios of the reactive to inert petrographic constituents, are listed in Table 1.

/TABLE 1 .....

## TABLE 1

## IMPROVEMENT IN SWELLING PROPERTIES OF SOME OF THE LOW ASH CONCENTRATES

| Origin of coal | | Product sample | | Low ash concentrate | |
|---|---|---|---|---|---|
| | | Ratio Reactives: Inerts | Swelling No. | Ratio Reactives: Inerts | Swelling No. |
| Klip River area coking coal | A | 3:1 | $4\frac{1}{2}$-5 | 28:1 | 9 |
| | B | 3:1 | $1\frac{1}{2}$-$3\frac{1}{2}$ | 18:1 | $6\frac{1}{2}$ |
| Witbank blend coking coal | A | 4:1 | 2-3 | 19:1 | $5\frac{1}{2}$ |
| | B | 3:1 | 2 | 24:1 | $4\frac{1}{2}$-5 |
| | C | 3:1 | 2 | 49:1 | $5\frac{1}{2}$ |
| Non-coking coals | A | 2:1 | 1 | 14:1 | +9 |
| | B | 1:1 | 1 | 9:1 | 8 |
| | C | 1:1 | 0 | 4:1 | $4\frac{1}{2}$ |

Dilution of the product sample by mineral matter is an important contributory factor but it appears that the modification of the ratio in petrographic constituents by the elimination of inert material is the major factor responsible for the difference in swelling properties.

The fact that swelling coal can be concentrated from the so-called "non-coking" coals has been known for a very long time; also that not all of the low ash concentrates are suitable for carbonization purposes. However, very extensive work[5-15)] carried out over a number of years proved that the swelling coal fraction from the Witbank No. 2 Seam, for instance, is not only suitable for blending with straight coking coals but that it can also be economically extracted. This extraction will soon be undertaken on a very large scale and preliminary work indicates that it may also be extended to the "non-coking" coals of Natal.

/2.0 PRACTICAL .....

# 2.0 PRACTICAL APPLICATION OF COAL PETROGRAPHY

## 2.1 The Prediction of Coke Stabilities

The work undertaken at the pilot coke ovens of the Fuel Research Institute provides ample opportunity for experiments in this field.

In a comprehensive programme now being undertaken in connection with the recovery of swelling coals from the fines produced by collieries in Natal, large consignments were washed at low specific gravities and carbonized in gas-heated experimental coke ovens. Tests were carried out simultaneously in the wide (19 in) and narrow (15 in) ovens. Laboratory coking tests and petrographical analyses were carried out on all the charges concerned.

Some of the results obtained by following the scheme of Mackowsky and Simonis[16)] are recorded in the following tables. Table 2 gives a comparison between the values of the dry ash-free volatile matter, determined and calculated, and the G-index calculated from dilatometer results and microscopical observations. The coals are arranged in the order of decreasing rank from the top to the bottom of the table.

TABLE 2

COMPARISON BETWEEN THE DRY ASH-FREE VOLATILE MATTER CONTENT AND G-INDEX

| Origin of coal | | % Volatile matter (dry ash-free) | | G-index | |
|---|---|---|---|---|---|
| | | Determined value | Value calculated from microscopical observations | Calculated from dilatometer results | Calculated from microscopical observations |
| Vryheid coking coal | A | 25,5 | 24,3 | 1,003 | 1,077 |
| | B | 26,1 | 27,8 | 0,983 | 1,083 |
| Klip River coking coal | A | 27,2 | 27,4 | 0,896 | 1,084 |
| | B | 35,5 | 30,7 | 1,039 | 1,039 |
| Paulpietersburg coking coal | A | 38,8 | 36,2 | 0,957 | 0,718 |
| Witbank No. 2 recovered coking coal | | 34,2 | 35,6 | - | 0,577 |

The results appear to be reasonably satisfactory, apart from those obtained from the Klip River Coking Coal B which is reputed to be one of the best coking coals in the country but which is unfortunately a rather high volatile coal.

Tables 3 and 4 give the predicted and determined coke stabilities in terms of micum indices for cokes from the wide and narrow ovens, respectively.

TABLE 3

PREDICTED AND DETERMINED COKE STABILITIES FOR THE WIDE OVEN

| Origin of coal | | M40 | | M10 | |
|---|---|---|---|---|---|
| | | Predicted | Determined | Predicted | Determined |
| Vryheid coking coal | A | 80,9 ± 1,0 | 83,5 | 6,6 ± 1,3 | 8,3 |
| | B | 80,9 ± 1,8 | 82,3 | 6,3 ± 1,3 | 9,9 |
| Klip River coking coal | A | 82,9 ± 1,7 | 85,3 | 7,2 ± 1,3 | 8,5 |
| | B | 72,9 ± 2,6 | 80,0 | 9,4 ± 1,3 | 11,2 |
| Paulpietersburg coking coal | A | - | 71,4 | - | 9,8 |
| Witbank No.2 Seam recovered coking coal | | - | 69,7 | - | 15,7 |

TABLE 4

PREDICTED AND DETERMINED COKE STABILITIES FOR THE NARROW OVEN

| Origin of coke | | M40 | | M10 | |
|---|---|---|---|---|---|
| | | Predicted | Determined | Predicted | Determined |
| Vryheid coking coal | A | 83,7 ± 0,6 | 83,6 | 7,6 ± 1,1 | 8,0 |
| | B | 86,9 ± 1,8 | 79,5 | 6,8 ± 1,4 | 11,6 |
| Klip River coking coal | A | 88,1 ± 1,1 | 82,3 | 7,2 ± 1,3 | 8,5 |
| | B | 83,1 ± 2,7 | 81,0 | 9,4 ± 1,3 | 11,5 |
| Paulpietersburg coking coal | A | - | 71,4 | - | 8,3 |
| Witbank No.2 Seam recovered coking coal | | - | 72,6 | - | 12,9 |

The results recorded in Tables 3 and 4 indicate that the $M_{40}$ values for both the wide and narrow ovens vary somewhat; those of the wide oven show lower predicted than determined values while those for the narrow oven follow the opposite trend.

The predicted and determined $M_{10}$ stabilities for both the wide and narrow ovens show remarkable agreement, with the predicted values for both ovens slightly on the low side.

The system appears to work reasonably well in the case of high rank coking coals such as the top four listed in the tables. With the less mature coals it appears to break down and the values become completely unrealistic. For $M_{40}$ they are boosted out of all proportion while the opposite is valid for $M_{10}$.

The determination of the G-index by means of the dilatometer becomes impossible for the lower rank coking coals as they show only a contraction and no dilatation and one has, therefore, to rely on microscopic observations only. In this respect it appears from the experiments conducted that the predicted stability values tend to become unreliable when the G-index, as determined microscopically, falls below the value of 0,7.

The Roga index has already found considerable favour as a substitute for the dilatometer test in South Africa, particularly in view of the fact that it gives consistent results on the low rank blend coking coals where only a contraction and no expansion is recorded by the dilatometer.

The relationship between the dilatation and the Roga index of a coal, as found by Müller[17)], is illustrated in Diagram 3. The relationship still follows a fairly broad band but by the use of more sophisticated apparatus it is hoped to narrow this down in the near future.

It can be observed that the Roga index assigns a value to the coking potential of a coal in the area below the abscissa where it is difficult, if not impossible, to interpret the real meaning of the contraction as recorded by the dilatometer.

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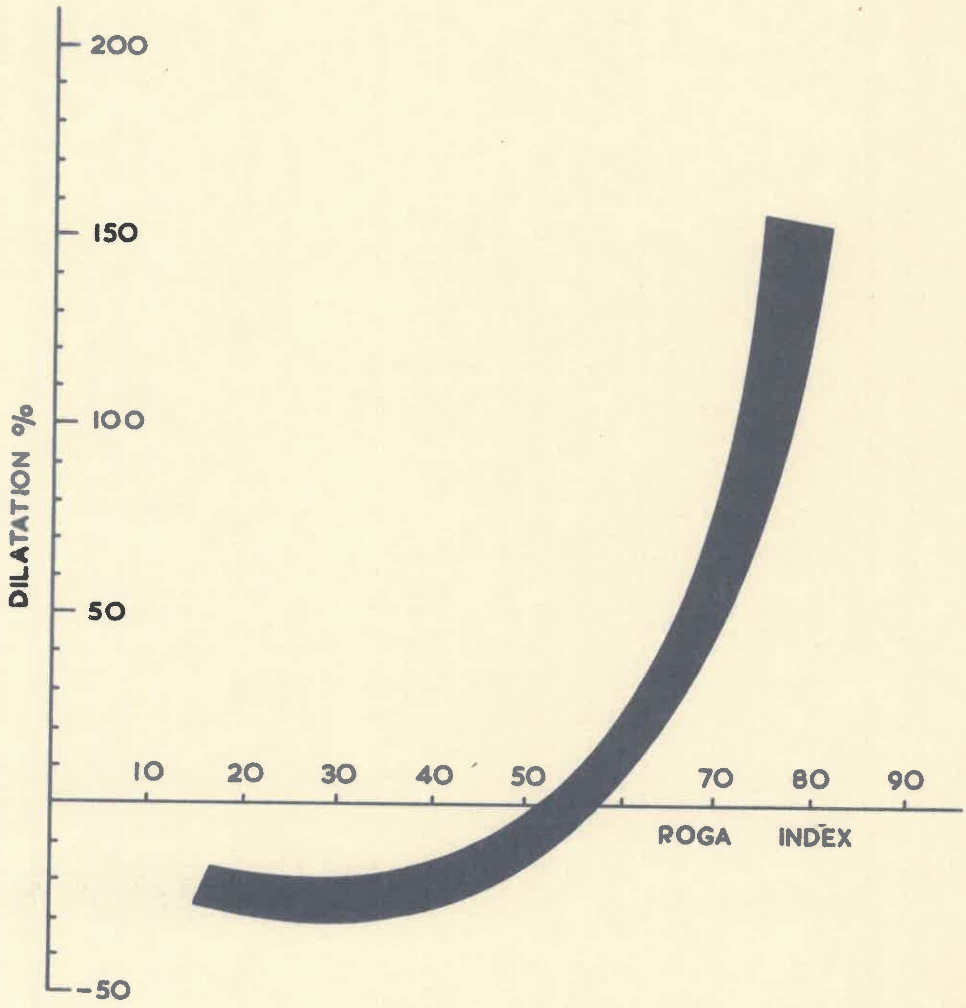
DIAGRAM 3




RELATION BETWEEN DILATATION AND ROGA INDEX

One of the major problems encountered during the investigation was to find a suitable low volatile anthracite to serve as the base material for the determination of Roga indices. Consistent results could not always be obtained when anthracites from different localities were used.

Stereoscopic examination of the minute anthracite particles prepared for the experiment proved the existence of two variations in their exterior appearance. These can best be described as distorted cubes with rather uneven surfaces and slabs with relatively smooth surfaces. The latter form, in particular, is responsible for the inconsistent results. This deviation in form of the particles, together with other physical and chemical characteristics such as the wettability properties of the anthracites, are probably due to the differentiation in the degree of polymerization of the coal in the course of its metamorphism.

## 2.2 Detection of the Influence of Dolerites on Coal by means of Reflectance Measurements

The coal seams in South Africa are all horizontally disposed and the underground workings of a major colliery may exceed 10 or more square miles. It is, therefore, not unusual that coal in one or more sections may be affected by a dolerite dyke where it cuts through the seam, while coal in other sections remains unaltered.

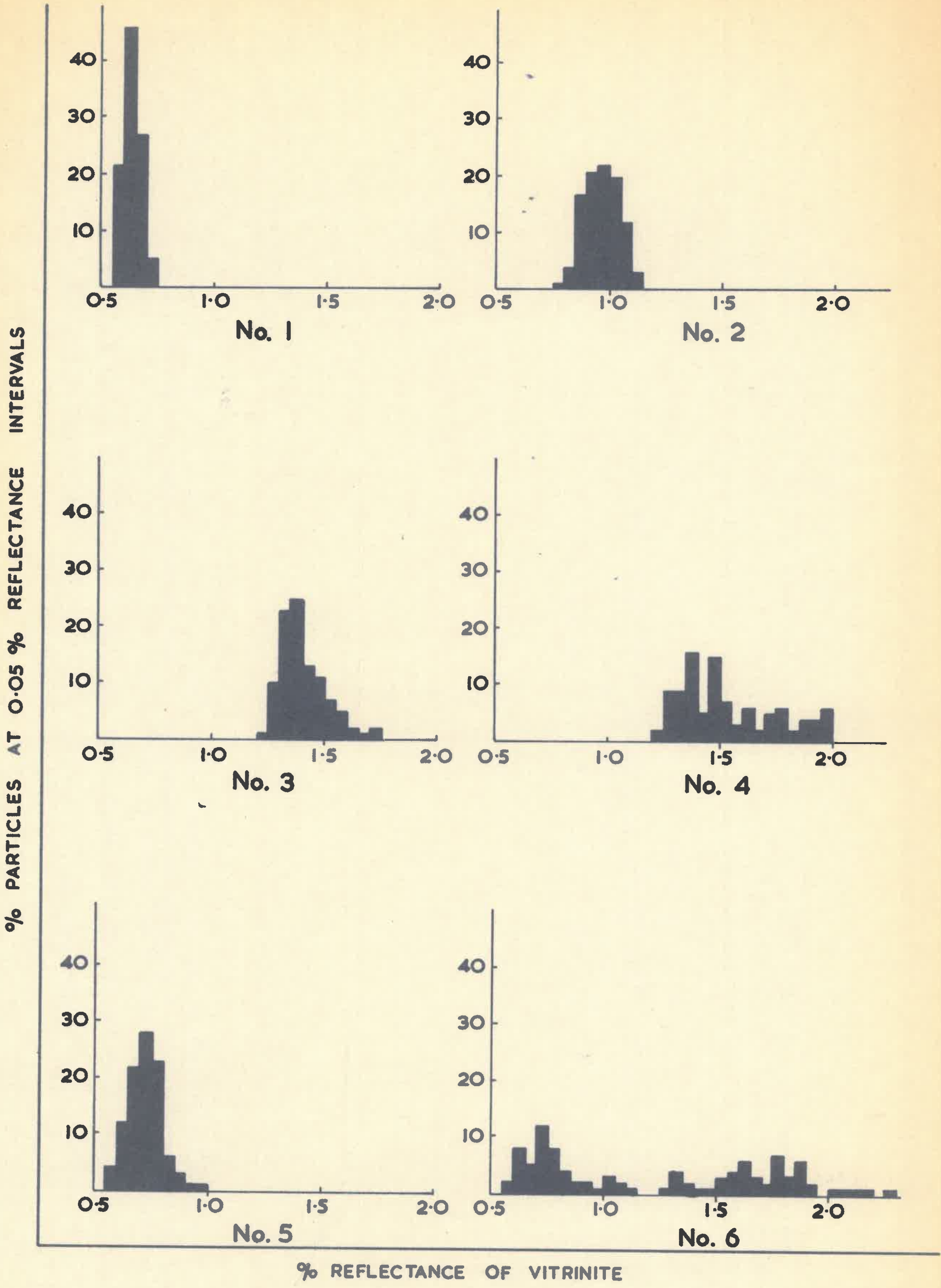
In mining practice, coal from the different underground sections are continuously fed to surge bins at the surface prior to being mechanically cleaned.

Thus, alteration of the mined product may at first proceed slowly as the result of gradual encroachment on the affected area and dilution with unaffected coal from other sections of the colliery. Unless precautionary measures are taken, such as the continuous sampling and testing of the product, mixing of unaffected and affected coal may only be discovered at a relatively late stage when a general deterioration occurs, in the case of coking coals, of the carbonized product.

Since reflectance measurements show even slight metamorphic changes very well, they have been successfully

/applied .....

DIAGRAM 4




REFLECTANCE HISTOGRAMS OF VITRINITES

IN DIFFERENT COALS

applied in this particular field. It is thus not only possible to explain the deterioration of the carbonized product on the ground of metamorphic changes in the coal but they also serve to locate the source.

By way of illustration, Diagram 4 shows the reflectance histograms of a number of coals. Histograms No. 1 and 2 are of a normal blend coking coal and straight coking coal, respectively.

Histograms No. 3 and 4 represent coal sampled in the same colliery. No. 3 represents the normal product and No. 4 shows the deterioration in a certain section resulting from igneous activity. From the histogram it can be inferred that nearly 30 per cent of the coal as represented by the sample consists of anthracitic material.

The influence of dolerite intrusions on the properties of a coal can best be observed from the reflectance of the vitrinites recorded in Histograms No. 5 and 6 which are representative of a low rank Orange Free State coal derived from two collieries of which the holdings adjoin. One colliery extracts coal from an area relatively free of dolerites and the histogram obtained is represented by No. 5. The other colliery extracts coal much affected by doleritic intrusions, the effect of which can be observed in Histogram No. 6. This histogram bears evidence of a product covering the whole reflectance range.

## CONCLUSION

In conclusion it can be stated that by virtue of their physical, chemical and petrographic constitution South African coals are somewhat less amenable to coal petrography than the coals of the Northern Hemisphere. There appears to be ample evidence that their petrographical study, with the aim of practical application of the results in technological fields, may hold considerable promise.

(SIGNED) B. MOODIE
PRINCIPAL RESEARCH OFFICER

PRETORIA.
29th April, 1971.
/TW

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