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THE QUALITY OF CANADIAN METALLURGICAL COALS IN THE JAPANESE AND WORLD MARKETS

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MARCH 1977

For Presentation at the 79th CIM Annual General Meeting, Ottawa, April 20th, 1977.

ENERGY RESEARCH PROGRAM
Energy Research Laboratories
Report ERP/ERL 77-34 (OP)

The Quality of Canadian Metallurgical Coals in the Japanese and World Markets

by

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Abstract

The quality requirements for cokes for large blast furnaces, especially those in Japan, are reviewed. High coke strength is achieved by optimum blending using premium coals from several world sources. Canadian coals play an important role in the production of high-strength cokes from multi-component blends, and their quality allows them to compete with coals from other more geographically favourable sources, such as Australia. Carbonization and analytical data acquired from CANMET investigations using Canadian metallurgical coals are stored in a computer for ready access. Some of these data are used in this paper to demonstrate the importance of Canadian coals to the Japanese coal blending philosophy. Changes in carbonization technology are discussed which may provide a place for lower quality Canadian coals in world markets.

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Introduction

At this time hopefully of the end of a general recession in the world's steel industry and at a time when coal long-term purchase contract talks on new coal development projects with Japanese steelmakers are in progress, it is perhaps pertinent to review the standing of Canadian export metallurgical coals in world markets, especially Japan, from the technical viewpoint of the coke- and iron-maker.

Japanese steelmills have been forced to cut back on their iron and steel production because of the rise in price of the principal raw materials (iron oxide lump and pellets as well as coal) since the international oil crisis of about three years ago. At the same time, new coal development projects in Canada, Australia and other areas are reaching the point of definitive contract negotiations when metallurgical coal stockpiles in Japan are full and when Japanese negotiators are endeavouring to keep prices down to reduce steelmill operating deficits. Total metallurgical coal imports into Japan in 1976 were 57 metric million tons and Japanese steel production is variously predicted to increase only slightly from 108.2 metric million tons in fiscal year 1976 to 110 metric million tons or to as much as 116-117 million tons in 1977, depending upon the source of information.

The competitiveness of Canadian metallurgical coals vis-à-vis Australian coals must be influenced by the fact that Canadian coals are won in mountainous regions remote (1100 km) from the loading port often from steeply-dipping seams and in a harsh climate. By contrast, Australian coals from Central Queensland are won generally in highly-efficient strip-mining operations from flat, thick seams at only 200 km from the loading port with a considerably shorter distance to Japanese ports, although perhaps not to European ones. The anticipated continuing requirement for Canadian coals by Japanese steelmills results from both the strategic necessity of diversification of supply and the fact that many western Canadian metallurgical coals produce very strong coke when coked alone (as will be discussed later), assisting in the production of the high quality coke mandatory for the operation of jumbo-sized blast furnaces. However, Australian Queensland coals are generally higher in mean reflectance than coals from the properties currently under development in western Canada.

Priority coal development projects for which coal production should start by about 1980 are Gregg River (2 million tons/yr) and the Hosmer-Wheeler project of Kaiser Resources Ltd. (2 million tons/yr) in Canada and Norwich Park of Utah Development Co. (4 million tons/yr, 2 million for Japan) and the Gregory mine of the Broken Hill Proprietary Company Ltd. (3 million tons/yr, 2 million for Japan) in Australia. The Quintette project of the Denison Mines Group is also a priority project with the Japanese, together with Australia's Hail Creek and Nebo projects (5 million tons/yr, respectively). Other Canadian developments include Fording Coal's Eagle Mountain district and, further in the future, Sage Creek of Rio Algom Mines Ltd., and Line Creek of Crows Nest Industries Ltd.

This presentation will continue to review first of all coke quality requirements for large blast furnaces followed by blending techniques to obtain good coke using coals from several sources. The quality of Canadian coals will be discussed from a technical viewpoint and in relation to competing coals from other sources, utilizing metallurgical coal carbonization data from coals tested at CANMET and retrieved from a computer memory file. Finally, some newer developments in carbonization technology which may provide a place for lower-quality Canadian coals in world markets will be reviewed briefly.

Coke Quality Requirements for Modern Blast Furnaces

With the advent of very large blast furnaces for ironmaking (greater than $4000 m^3$ inner working volume, for example the Nippon Steel Corporation Oita Works No. 2 at $5070 m^3$) operating at high production rates (up to 2.4 metric tons/m^3/day), the importance of uniform size and high-strength coke to the blast-furnace operator has become critical. Indeed, the availability of iron ores, pellets and sinter of carefully controlled size and high iron content (~64 per cent) dictates that of the blast-furnace burden components, coke quality requires the most attention and specifications for individual coals have to be evaluated in the light of modern blending practices.

The role of coke in the blast furnace is not only as a reductant and source of fuel but also to maintain permeability, especially in the bosh area, in order to ensure uniform gas flow and high productivity. Coke in large blast furnaces is especially subject to mechanical breakage because of the great height between the stockline and tuyères. Operating parameters such as high-temperature blast and high top pressure also contribute to increased requirements for strength and other properties of coke.

The specifications for good blast furnace coke demanded by one Canadian steel company[1] are given below:

TABLE 1 Canadian Specifications for good blast furnace coke

Analysis	Limits (per cent)
Ash	< 8.0
Volatile Matter	< 1.0
Sulphur	< 0.70
Alkali Oxide in Coke	< 0.20
Phosphorous Pentoxide in Coke	< 0.27
ASTM Stability	≥ 55.0

Size distribution is an important parameter, there being a tendency to minimize the proportions of +80 and -20mm fractions. Coke chemistry is judged to be less significant than the physical properties, although ash and sulphur are held at the lowest economically justifiable values.

Reactivity to carbon dioxide should be low and porosity uniform. The specifications quoted in Table 1 are, of course, not always attainable and an example of the quality of coke charged to the NSC Oita No. 1 blast furnace (4158m^3 inner working volume) is given in Table 2[(2)]:

TABLE 2 Quality of coke charged to NSC Oita No. 1 B.F.

Ash	11-12 per cent
Sulphur	0.55-0.65 per cent
Strength JIS DI^{30}_{15}	>93.5 " "
JIS DI^{150}_{15}	>81.5 " "
Mean Size	47-50mm
Size Range	30-75mm

An increase in the ash content leads to an increase in coke rate and slag volume, causing a decline in productivity, and a decrease in the coke strength index can be related to a decline in furnace permeability, again underlined the importance of high quality coke to the blast-furnace operator.

Coal blending for Cokemaking

The importance of coke strength to blast furnace operation has just been reviewed. High-strength is achieved in practice by blending coals of different volatile matter contents, each component contributing to the ultimate strength. The requirement for the use of Canadian coals in blends and the effect that these individual coals have on coke strength is the key to their use in world markets.

In North American cokemaking practice, high-volatile (hv) coals, which shrink excessively when carbonized alone and produce weak coke, are blended with low-volatile coals (lv) which themselves produce strong coke but their expanding properties exclude their use alone in slot-type ovens. Western Canadian coals, in the main, fall in the medium volatile range (mvb) and are "self-cokers", although coals from this rank are sensitive to significant changes in their expanding characteristics with changing operating conditions (e.g. coking rate and oven bulk density).

The blending of coals to make high quality coke depends upon the relationship between the coal rank and the coking properties of the coals, i.e. the ability of the reactive coal macerals to "glue" together the inert macerals, as the coal passes through its plastic temperature range upon heating. Coal rank is measured by volatile matter or, more accurately, by the vitrinite mean reflectance ($R_{\bar{o}}$). The petrographic method, described elsewhere (for example, reference 3), relates strength index (S.I.) to composition balance index (C.B.I.) based on petrographic determination of the quantity and quality of reactive macerals and the quantity of inerts. Detailed descriptions of these terms will not be given here, but S.I. is in some way related to strength of coke structure and the C.B.I. is considered to be a measure of the caking propensity of the coal.

Kojima[4] at Nippon Steel Corporation (NSC) has used this petrographic method of evaluation to compare coals imported into Japan (Figure 1). The iso-coke strength curves were plotted on the diagram using JIS DI^{30}_{15} values from test oven cokes. The shaded area represents what is considered to be the ideal blend (too high a C.B.I. indicates that there are insufficient reactives to produce adequate bonding and too low a value indicates that too porous a coke would be produced). Canadian coals are favourably located to blend with Japanese very highly fluid coals as well as American hv coals, and New South Wales "soft" coking coals. However, the mean volatile matter of the blend should be in the range 29-33 per cent. A computerized automatic petrographic system has been developed at NSC[5] to evaluate the coking properties of coals which is claimed to be more accurate than the manual method; the technique is finding application in coal blending and quality inspection of purchased coals.

Perhaps one of the currently most popular methods in use today for depicting the optimum coal blend requirements for cokemaking is that developed by Miyazu et al[6] which relates mean vitrinite reflectance (coal rank) to the logarithm of the maximum fluidity as measured with the Gieseler plastometer (Figure 2). The solid line in Figure 2 (known as the MOF Diagram) connects U.S. coals with low inert content to Japanese highly-fluid and Australian lv coals, giving a fluidity maximum at a mean reflectance of 0.9-1.0 per cent. Canadian coals fall below the curve in the fourth quadrant because their relatively high quantity of inerts gives a lower maximum fluidity than other coals with a similar mean reflectance.

The MOF diagram is conveniently divided into four quadrants, coals from quadrants I and II being necessary to maintain blend fluidity (optimum values in the shaded rectangle: $R_{\bar{o}}$ between 1.20-1.30 and maximum fluidity between 60 and 1000 ddpm), and from quadrants I and IV to maintain high strength. Coals in quadrant III with low rank and fluidity, merely act as a carbon source. Thus, Canadian mvb and lvb coals would seem to be an ideal choice for blending with Queensland northern Bowen Basin coals, but there must be sufficient overlap of the component fluidity temperature ranges to produce a strong coke. A bridging coal, such as a Japanese hv coal, would help to overlap component coal fluidity temperature ranges.

The necessity for fluidity overlap is vital to blending predictions, but carbonizing the coals individually allows an assessment to be made of their relative contributions to the strength of coke from a multi-component blend. Such an exercise has been done by Miyazu et al[(7)] (Figure 3), the high-reflectance Canadian coals giving high JIS DI^{30}_{15} values, underlining the importance of their quality in coal blending to produce maximum strength blast-furnace cokes.

In concluding this section, mention should be made of the use of dilatation as the caking parameter in coal blending. The relationship developed by Simonis, Gnuscke and Beck[(8)] is used in Europe to predict coke strength from Ruhr dilatometer measurements (Figure 4). The quantitative blending parameter, known as the G-Factor, used in this method does not seem to apply to western Canadian coals. This factor has been found not to apply to U.K. coals above about 34 per cent volatile matter and a formula has been developed[(9)] which predicts the total dilatation of a binary blend from the dilatation curves of the components. Also in the U.K., semi-coke contraction in the post-plastic temperature range measured with a high-temperature dilatometer is being used in optimum blend prediction exercises[(10)]. Figure 5 shows coals imported into Japan on the basis of Audibert-Arnu dilatation results plotted against volatile matter[(2)], again showing a "window" for optimum coal blends.

It is worth noting that petrographic analysis of individual coals has reached such a stage of development that empirical pricing formulae are being developed with petrographically-determined maceral and caking parameters as variables. However, the value of such formulae is open to discussion.

Typical values for caking properties of western Canadian coals have been indicated in the previous figures and, for comparison purposes, export contract specifications for two coals are compared with average specifications for two coals from the north central Bowen Basin of Queensland, in Table 3. These Australian coals represent perhaps the biggest competitor to Canadian coals in the world market.

TABLE 3 Comparison of Export Specifications for selected western Canadian coals and north-central Queensland coals

	Company	Total Moisture (%)	Ash (%)	V.M. (%)	Total Sulphur (%)	FSI
Canada	McIntyre Porcupine Mines Ltd. (Smoky River)	6.0	7.0	17.5	0.5	7/9
	Kaiser Resources Ltd. (Balmer)	8.0	9.5	19/22	0.4	6/8
Australia	Saraji*	10.0	10.0	19.5	0.65	8/8.5
	Goonyella*	10.0	8.0	26	0.55	6/8

* Utah Development Company

Approximately 25 per cent of these Australian coals are destined for European markets and European and South American interests in western Canadian coal properties under development would indicate that markets in these areas will soon be opening up.

Whilst this discussion has related to the export of western Canadian coals, Cape Breton coal may also be exported to Japan. The Devco (Cape Breton Development Corporation) hv blend has the following approximate analysis: moisture, 7.5%, ash 3.0%, sulphur 1.11%, V.M. 35.7%, and the mean maximum reflectance is about 0.92 per cent. The high rank and maximum fluidity (>20,000 ddpm) makes this coal an excellent blend component, especially if western Canadian low-fluid coals are also included in the blend.

Carbonization data from western Canadian coals

Over the past 15 years, both single metallurgical coals and coal blends have been carbonized in 230kg movable-wall test ovens at CANMET (formerly the Mines Branch). As well as the evaluation of U.S. coals for use in the coke ovens of the Canadian steel industry, western Canadian coals have been evaluated for the export market. Coal analytical and thermal rheological data, petrographic measurements, coke quality data from the oven tests, and geographical information together with seam characteristics have been stored in a computer memory file at EMR in Ottawa for easy information retrieval. This information is a contribution to the computer-assisted National Coal Inventory. At present, there are approximately 500 entries encompassing coals both from producing mines and including adit samples from exploration projects. This section presents quality data for western Canadian coals as retrieved from the computer memory file.

Table 4 presents an example of the information which can be retrieved from the computer memory file, although the information is too general to be of much use. The mean values for volatile matter and mean reflectance are given for all coals by province (Alberta and British Columbia) and by two areas (Mountain Park and Peace River).

TABLE 4 Average Volatile Matter and Mean Reflectance Values by area for coals in the computer memory file.

	Alberta	British Columbia	Mountain Park Area	Peace River Area
Volatile Matter	21.92	24.54	23.73	25.01
Mean Reflectance	1.33	1.16	1.24	1.19

Also, carbonization data from the file have been plotted using the same axes as in Figures 1, 2 and 5. Inspection of the experimental points in Figures 6 to 10 indicates immediately that the Japanese diagrams at best only provide a guide to the blending characteristics of Canadian coals with respect to other coals. Attempts were made on Figures 6 and 7 (Strength Index versus Composition Balance Index) to draw iso-coke strength lines through the experimental points, the coke quality data being obtained from test oven (230 kg) data as was done by Kojima[4]. The two cases of JIS DI^{30}_{15} (Figure 6) and ASTM Stability (Figure 7) were considered. General trends were discernible, especially at Composition Balance Indexes of less than 2 although these iso-strength lines should only be considered as guides and give too wide a range of values to be of much practical use. Values of maximum fluidity and mean reflectance put some of the western Canadian coals entered in the computer memory file in quandrants other than IV in the MOF diagram (Figure 8). In Figure 9, however, values of the dilatation (Ruhr as opposed to Audibert-Arnu) and volatile matter put the greater proportion of western Canadian coals in the area outlined in Figure 5, and seemingly this method for displaying the blending properties of coking coals may have greater applicability than the more popular MOF diagram.

In conclusion, data obtained from western Canadian coals carbonized in CANMET 230 kg movable-wall ovens in general do not group these coals in specific areas on diagrams used to predict coking coal blending characteristics. However, perhaps this is not unexpected as petrographically-determined parameters are operator sensitive and also depend on sampling, amount of mineral matter removal, and are sensitive to sample oxidation, as are caking parameters.

New Carbonization Technology

Coals of high rank ($R_{\bar{o}}$ > 1.2%) and high fluidity have traditionally been considered to be a basic requirement for the production of high quality coke. Coals available on world markets which meet these requirements are principally the U.S. lv prime coking coals but these are becoming more expensive and in shorter supply. Consequently, methods are being sought by coke-makers to reduce their dependence on these coals while at the same time, maintaining mean blend fluidity in the range to provide sufficient bonding but not to produce too porous a coke structure. If the quantity of these coals in a blend is diminished, then the necessary carbon may be provided by substitution of a lower quality, or perhaps oxidized, coal.

This requirement has led to the development of new coking technologies which attempt to increase blend caking propensity by modifying preparation practices, such as by increasing oven bulk density.

Some of these technologies which allow a greater use of marginally or non-coking coals in oven blends, are summarized below:

TABLE 4 New Coking Technologies

Technology	Effect during Carbonization
Preheating	- increase oven bulk density - increase oven productivity - use of marginally coking coals
Briquette additions to coke oven charges (formed coal)	- increase oven bulk density - pitch binder increases mean blend fluidity - replacement of 5 to 30 per cent of blend with non-coking coals
Use of artificial caking materials*	- increase blend caking propensity - substitute for American strongly-caking coals

* e.g. the CHERRY Process (Comprehensive Heavy Ends Reforming Refinery), in which a mixture of petroleum asphalt and coal powder is coked at 750°C[11].

The development of technologies to substitute non-coking coals for expensive highly-coking coals by artificially-maintaining mean blend fluidities, as well as favouring the continued use of western Canadian high-rank by low-fluidity metallurgical coals, also favours the opportunities for lower-rank and oxidized coals in the export market. Indeed, significant quantities of oxidized coals are being exported to Japan for utilization in formed coal plants.

With reference to artificial coking materials, the possibility should be mentioned of the use in cokemaking of the solid residue from the solvent refining of low-rank sub-bituminous and lignitic coals. A blend containing SRC from Prairie low-rank coals together with a western metallurgical coal might have been a worthwhile consideration for a B.C. tidewater integrated steel plant. Finally, the prospect of formed coke being a user of lower quality coals should not be forgotten.

Summary and Conclusions

In spite of the cut-back in raw material supplies for the Japanese steel industry, the high-quality of Canadian metallurgical coals make them a necessary coke oven blend component. Western Canadian coals are being used to a greater extent by the Canadian steel industry and the European and South American interests in coal properties indicate a favourable additional market to Japan.

Also, it was reported at the 10th Annual Conference of the International Iron and Steel Institute held at Osaka, Japan, in 1976 that a world steel demand growth rate of 4 per cent would require the increase in coking coal mining capacity by 180 million metric tons. Japan's estimated crude steel production in 1980 is about 135 metric million tons requiring annual coking coal purchase increments of 5 to 10 metric million tons to produce the necessary quantity of pig iron. Such an increase would auger well for the future exports of Canadian coking coals. The quality characteristics selected from a large population of western Canadian coals have been illustrated and new carbonization technologies could be anticipated to assist in the opening up of markets for lower-quality coals, which may be especially important in the light of increasing world coking coal requirements.

Acknowledgements

The writers are grateful to Mr. R.J. Donaldson of the Energy Research Laboratories, CANMET, for providing carbonization data from the EMR computer memory file and to Mr. K.F. Hampel for preparing the diagrams.

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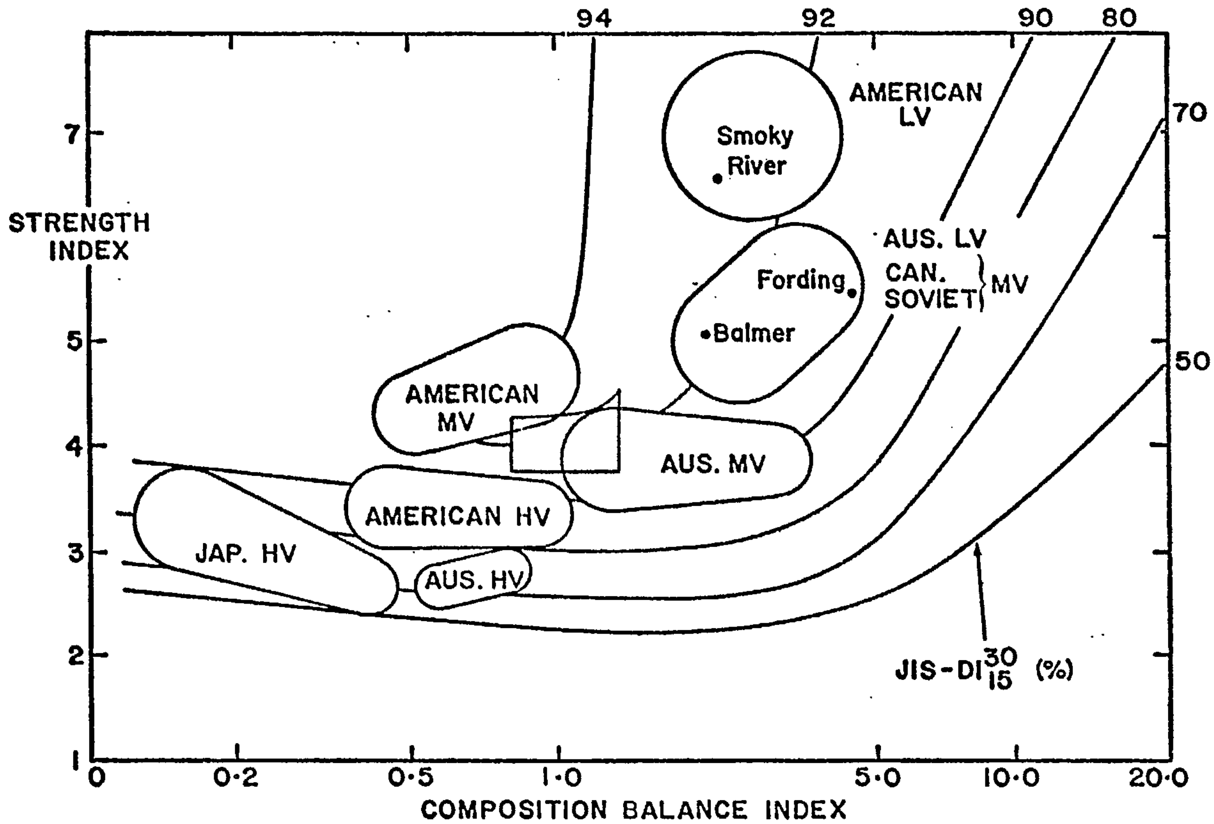
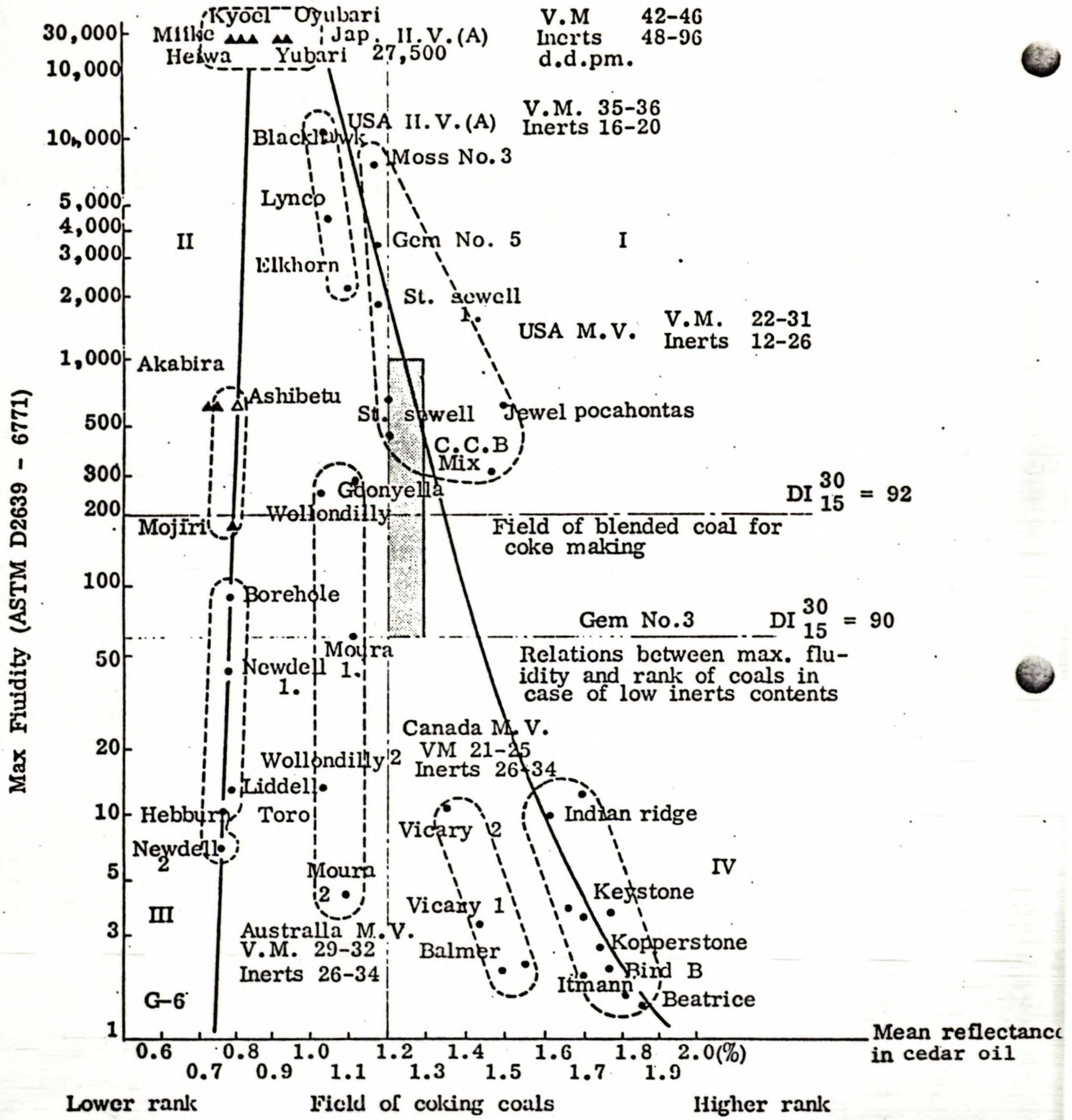


FIGURE 1. Relation between Composition Balance Index and Strength Index showing iso - JIS DI^{30}_{15} lines. (after Kojima[4]).



Note: V. M. contents are shown as percent on dry, ash free basis inert contents are shown as volume percent.

FIGURE 2. Relation between Maximum Fluidity and Mean Vitrinite Reflectance - MOF Diagram (after Miyazu[6]).

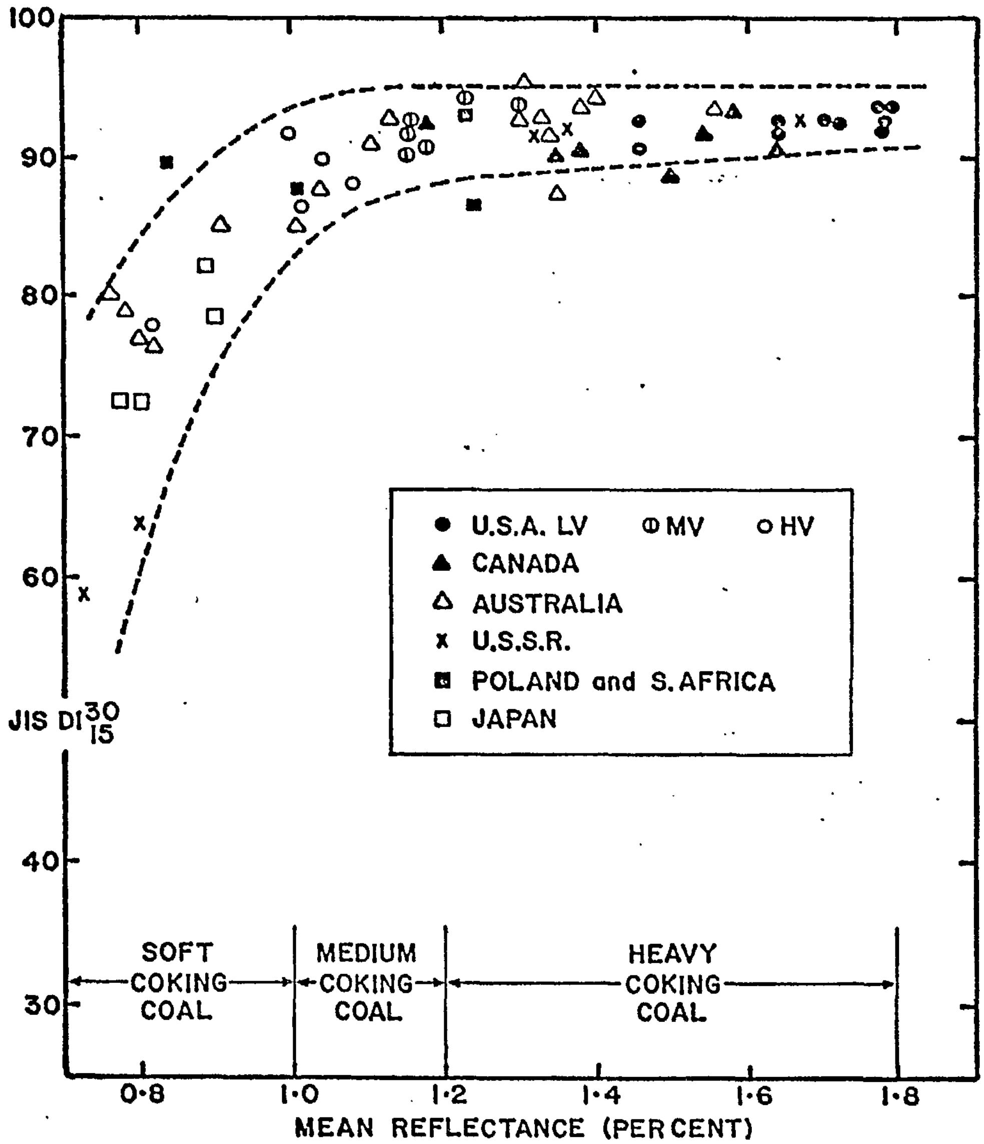


FIGURE 3. Relation between JIS - DI_{15}^{30} Coke Strength Index for single coals and Mean Vitrinite Reflectance (after (Miyazu[7]).

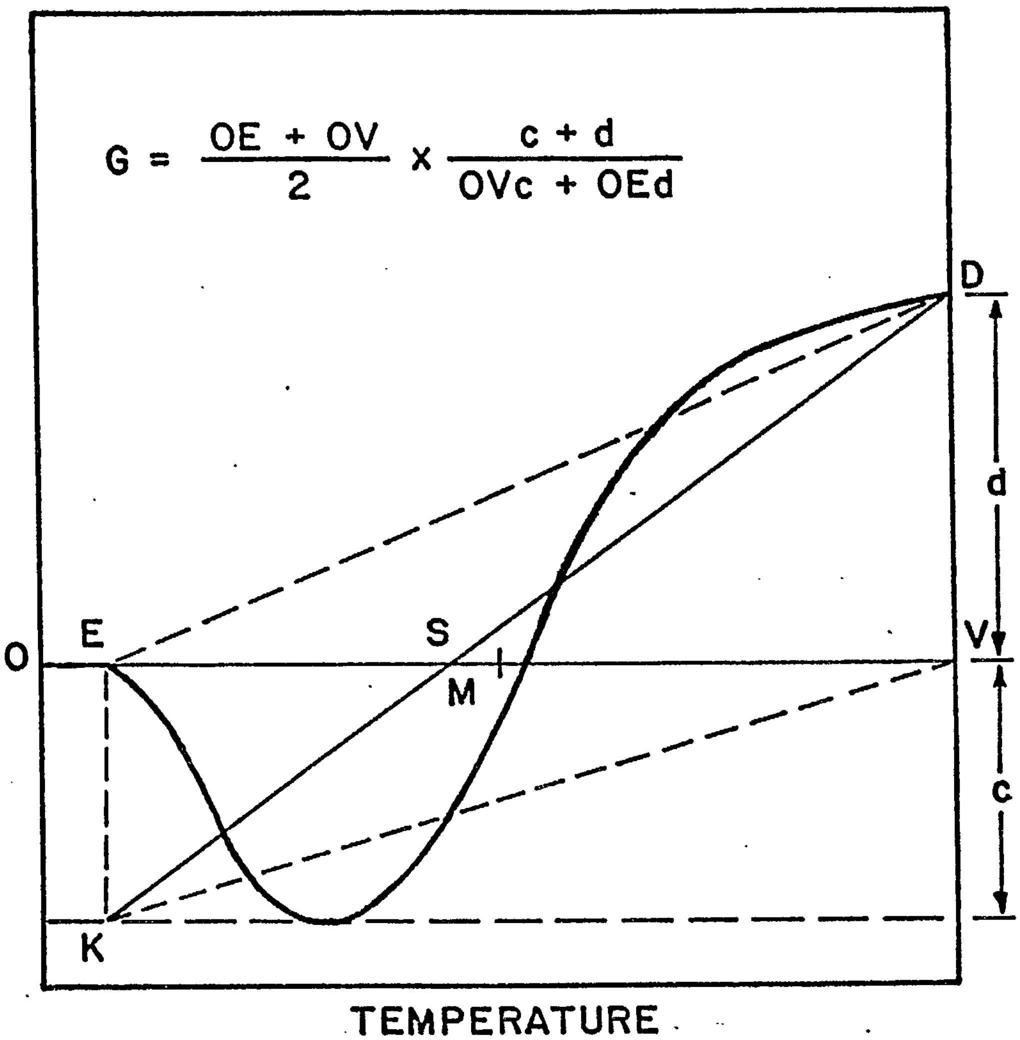


FIGURE 4. Definition of G Value from Coal Dilatation Curve (after Simonis et al[8]).

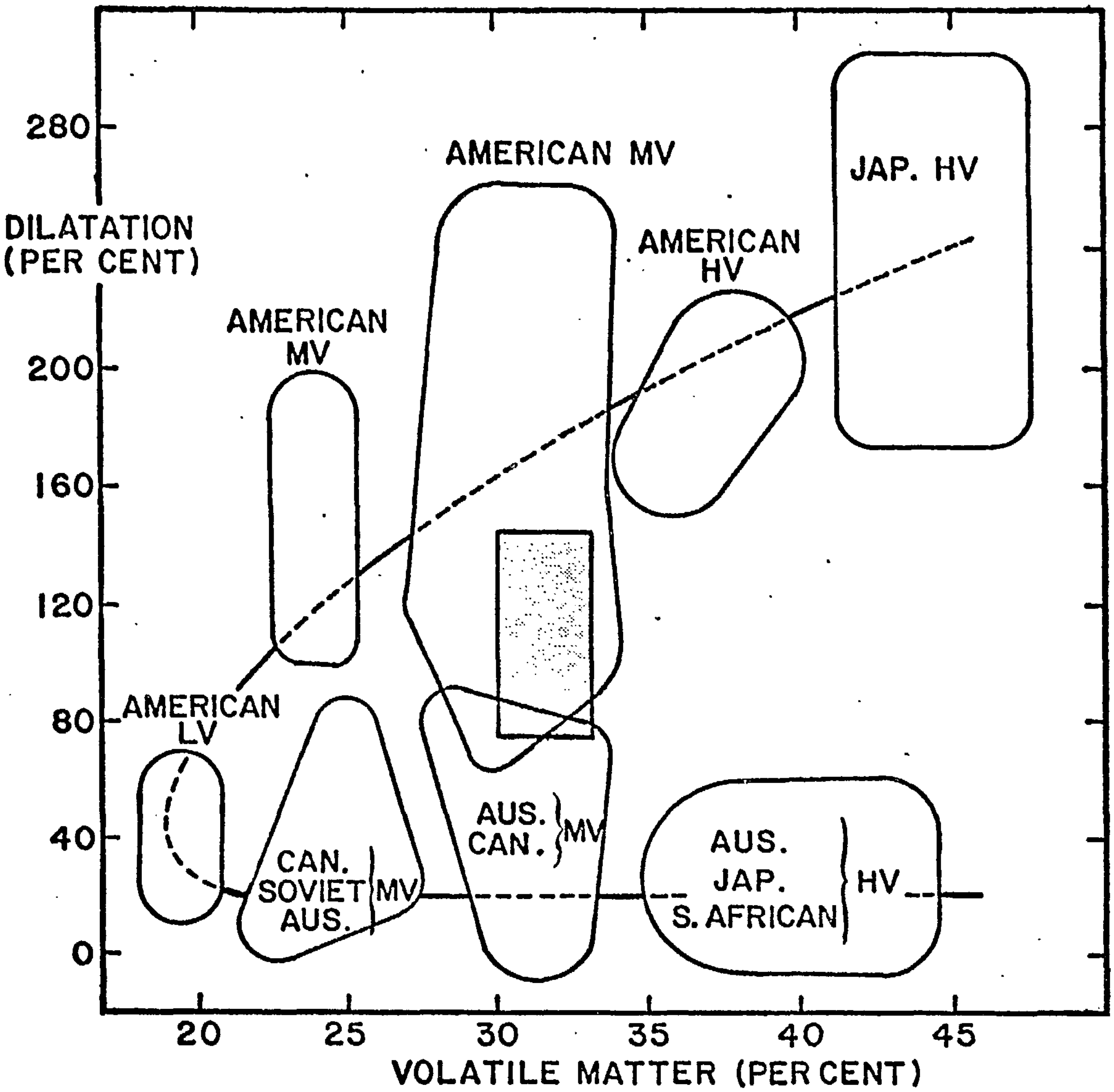
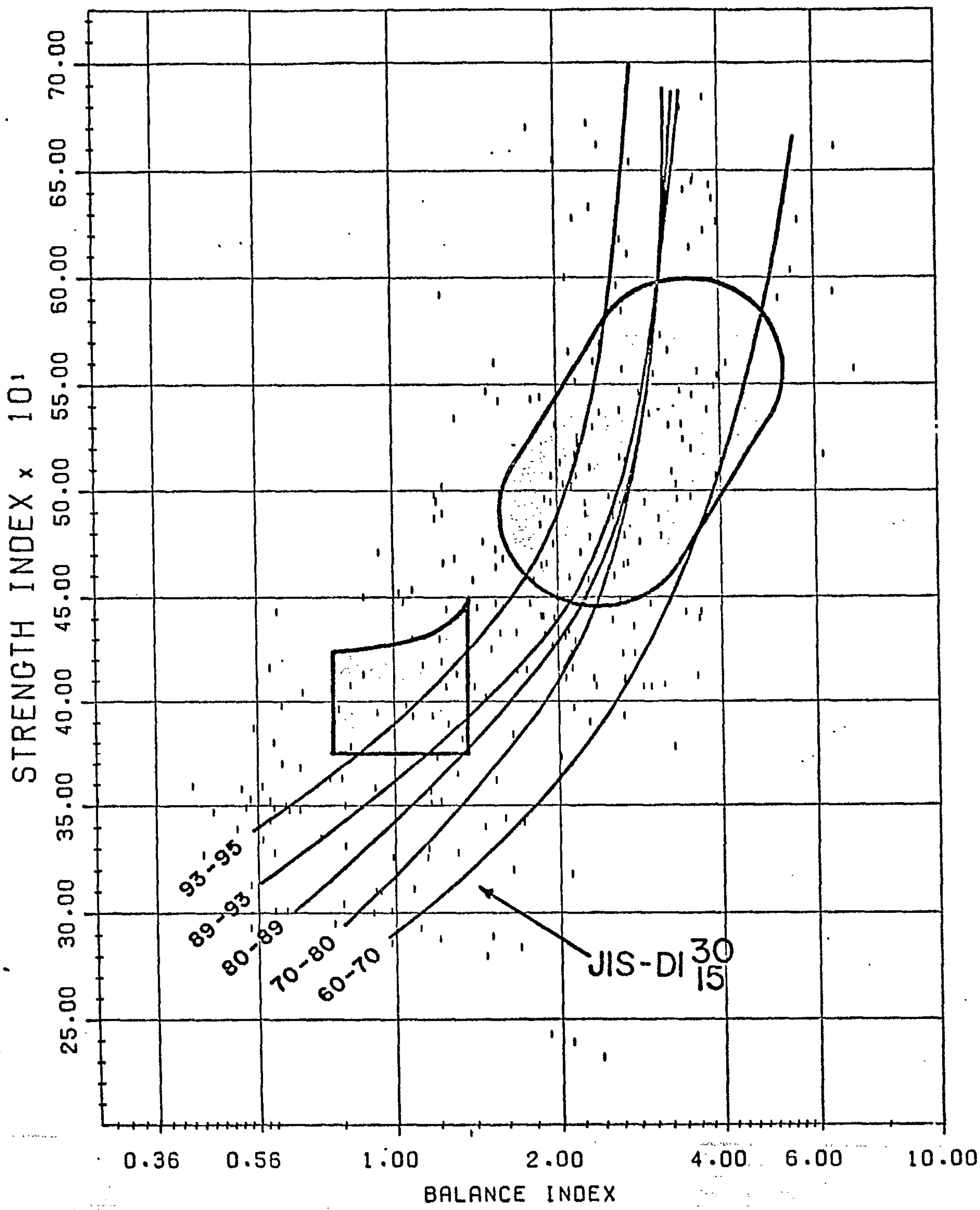


FIGURE 5. Relation between Audibert-Arnu Dilatation and Volatile Matter (after Matsuoka[2]).



STRENGTH INDEX VS BALANCE INDEX FROM COKE DATA BASE

FIGURE 6. Relation between Composition Balance Index and Strength Index for Western Canadian Coals showing iso - JIS DI^{30}_{15} lines.

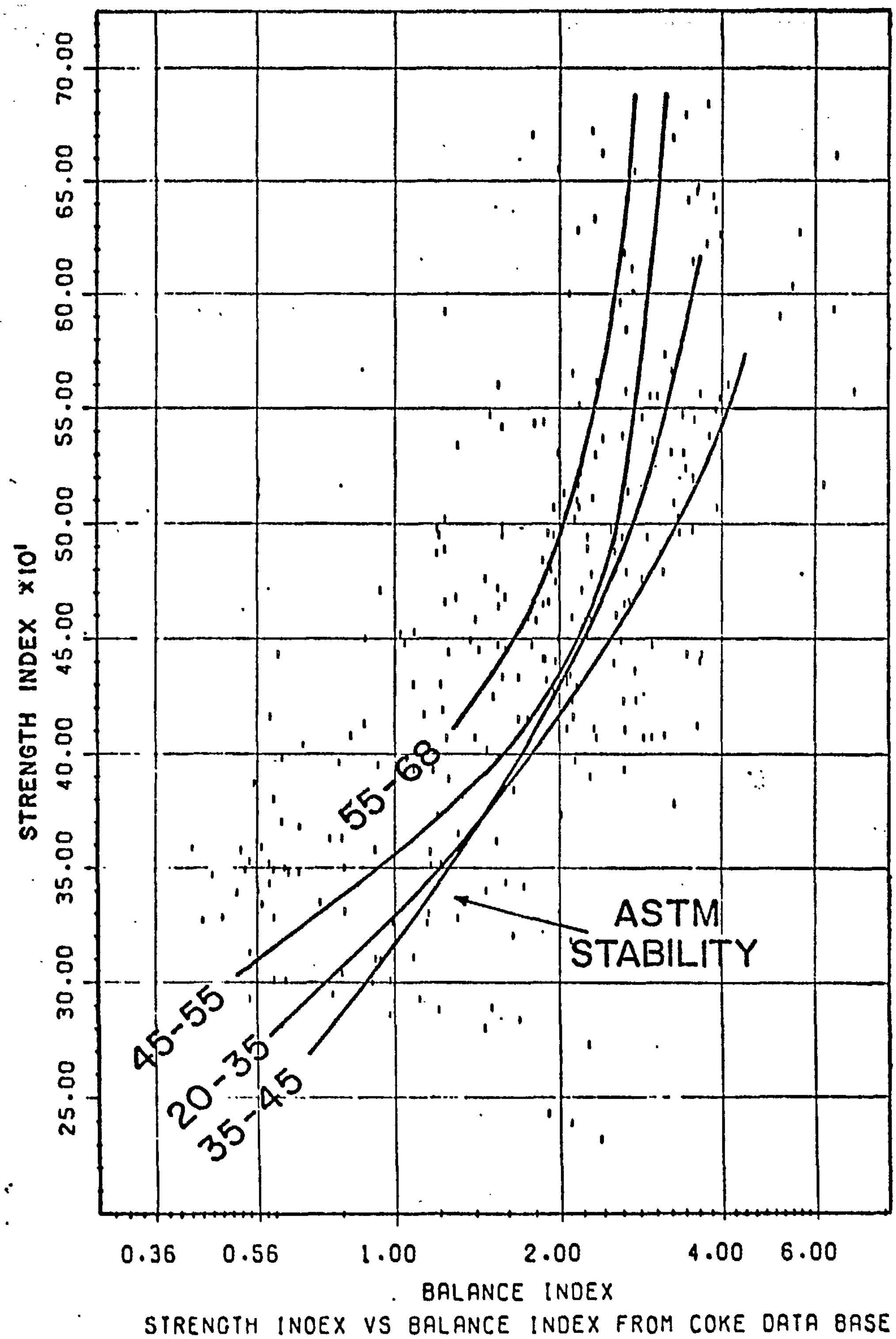


FIGURE 7. Relation between Composition Balance Index and Strength Index for Western Canadian Coals showing iso - ASTM Stability lines.

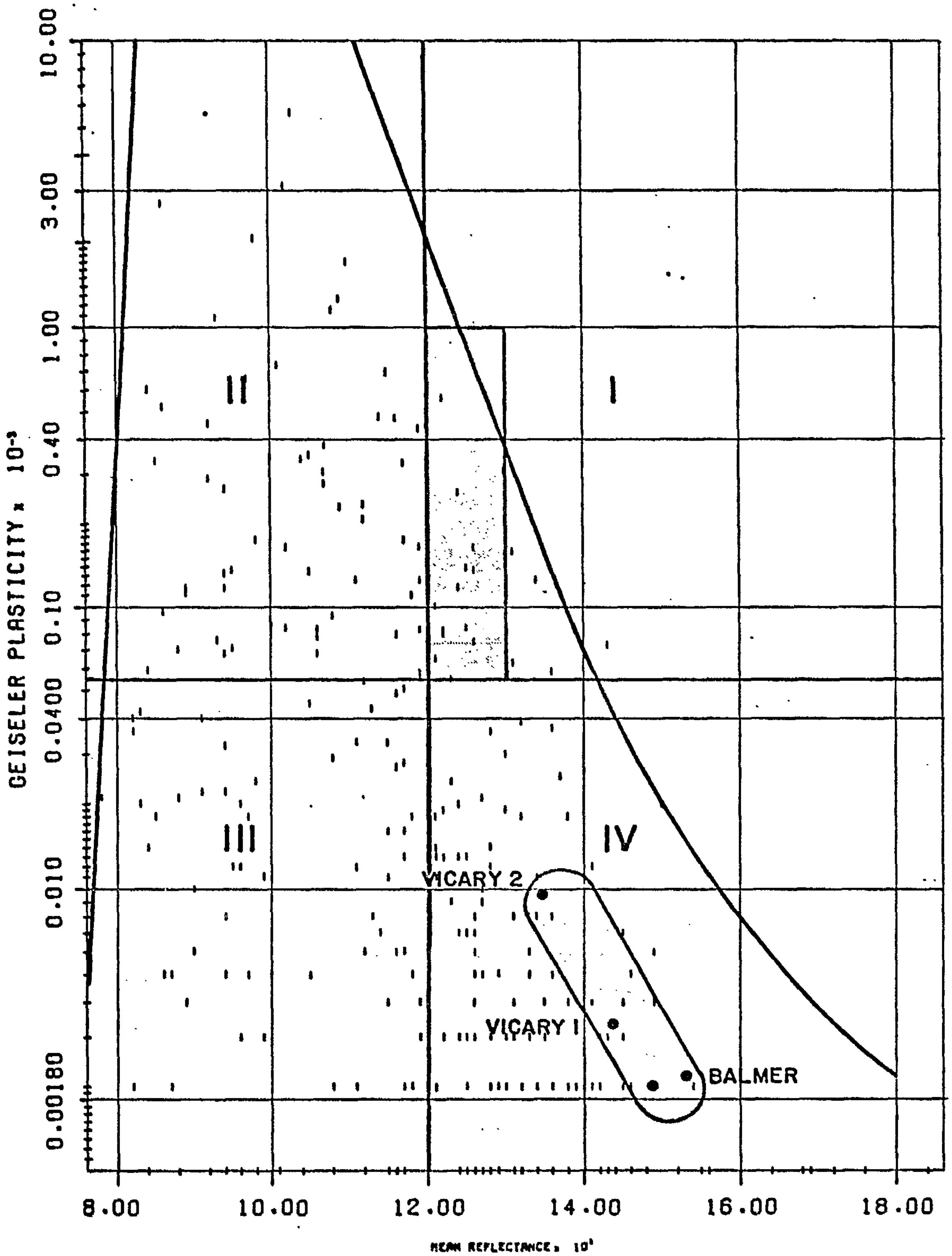


FIGURE 8. MOF Diagram showing Western Canadian Coals from the Computer Memory File.

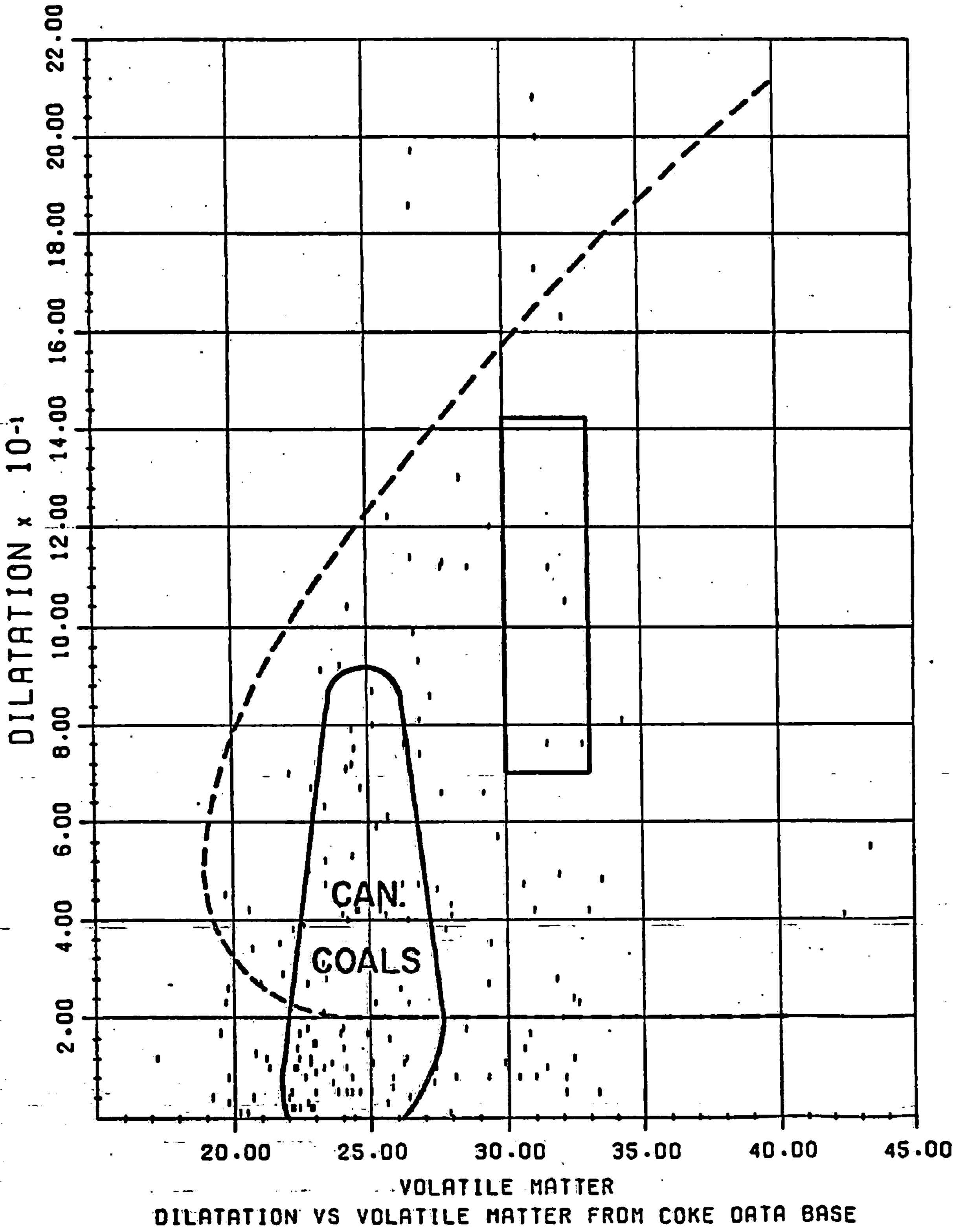


FIGURE 9. Relation between Ruhr Dilatation and Volatile Matter for Western Canadian Coals from the Computer Memory File.