AN

INVESTIGATION

OF THE

COALS OF CANADA

WITH REFERENCE TO THEIR ECONOMIC QUALITIES:

AS CONDUCTED AT McGILL UNIVERSITY, MONTREAL,
UNDER THE AUTHORITY OF THE DOMINION
GOVERNMENT

IN SIX VOLUMES
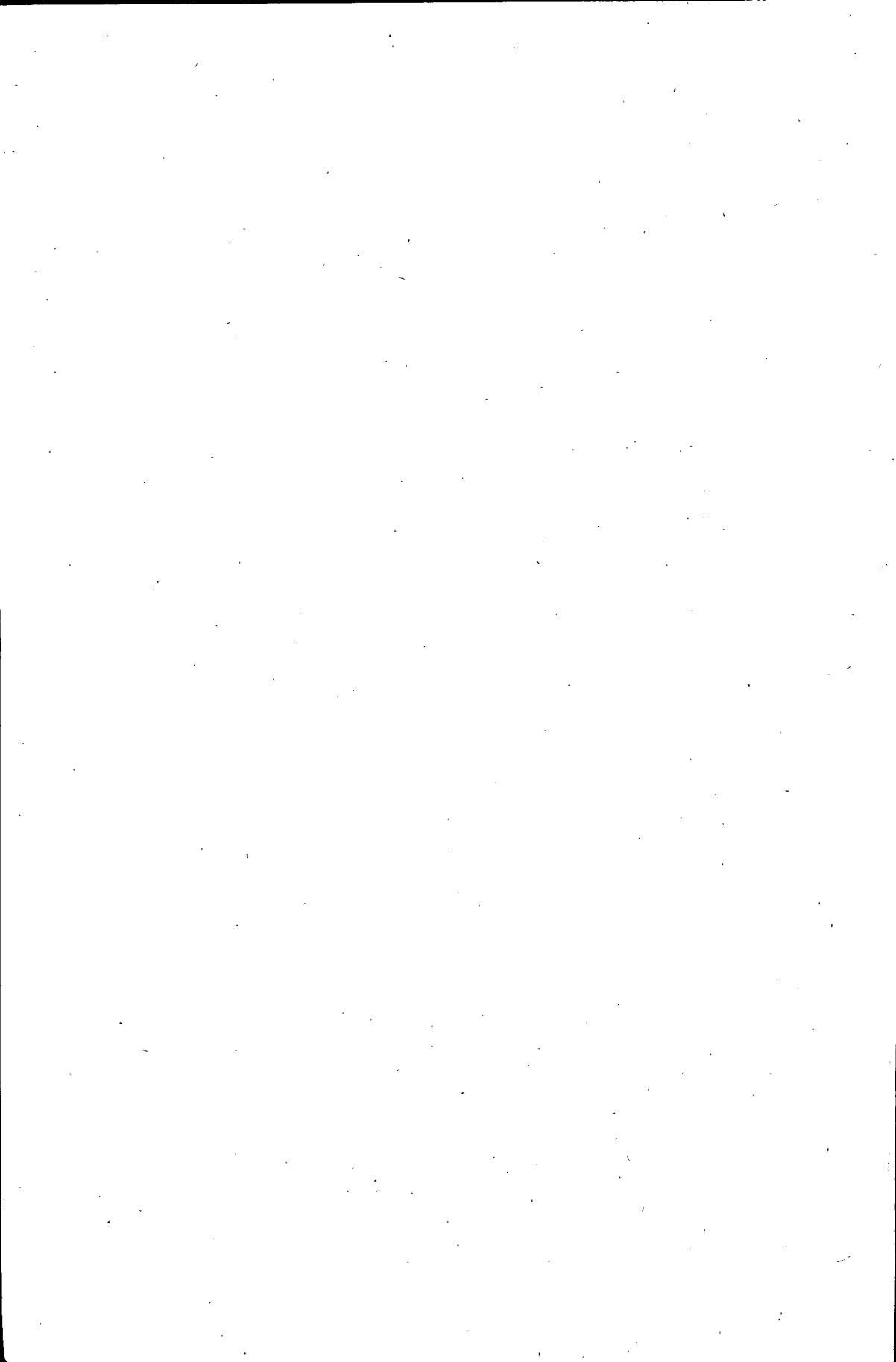
BY

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AND

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AND A STAFF OF SPECIAL ASSISTANTS.

VOL. VI

THE

COALS OF CANADA:

AN ECONOMIC INVESTIGATION

VOL. VI

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MANUFACTURE AND TESTING OF COKE

BY

EDGAR STANSFIELD AND J. B. PORTER

APPENDIX V

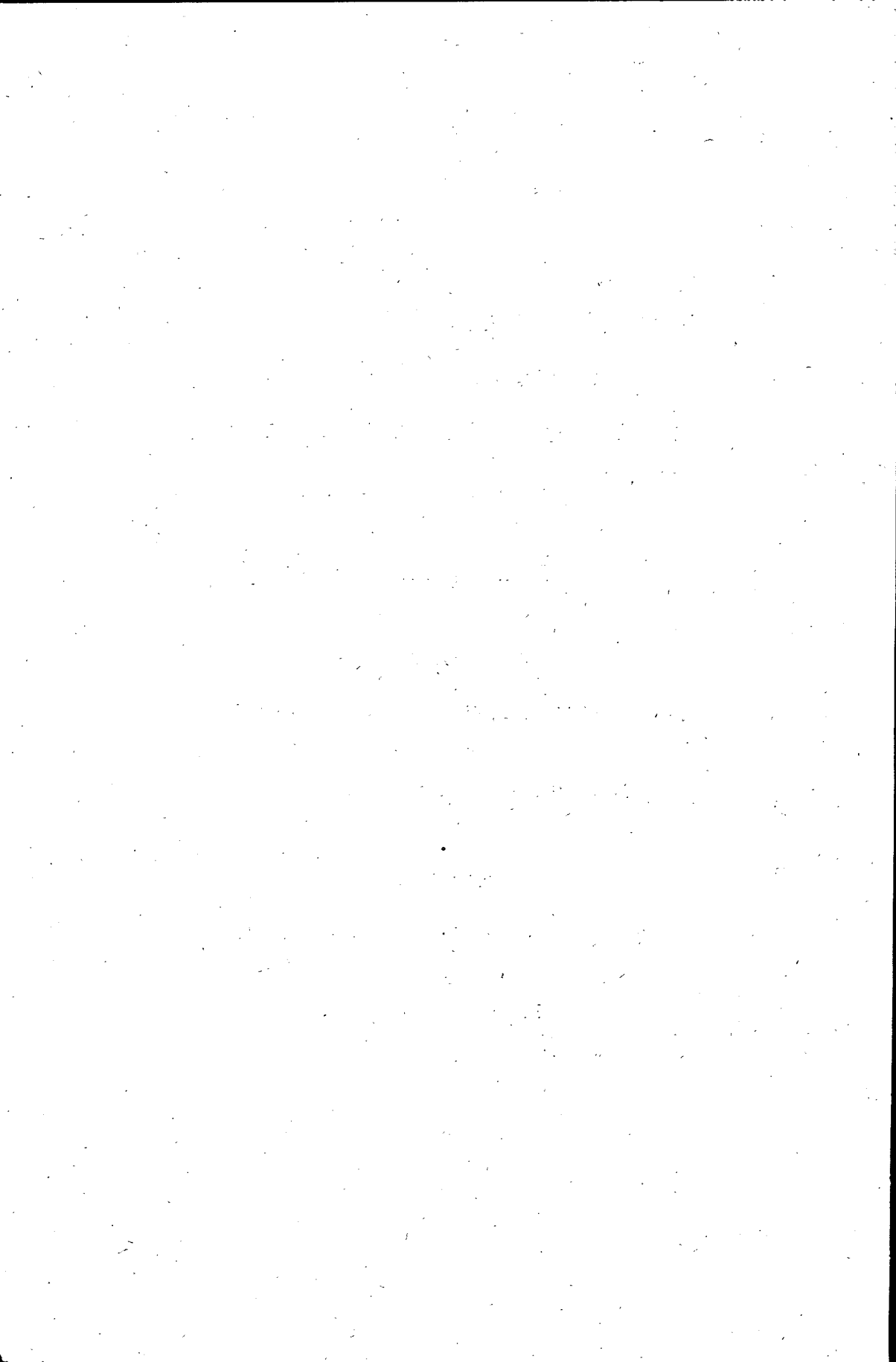## WORK OF THE CHEMICAL LABORATORY

BY

EDGAR STANSFIELD

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VOL. VI

INTRODUCTORY

In the autumn of 1906, the Canadian Government, through Dr. A. P. Low, Director of the Geological Survey, decided to undertake a study of the fuels of the Dominion, somewhat on the lines of the fuel tests which had already been commenced by the United States Geological Survey. But inasmuch as the Government had not, at Ottawa, any suitable mechanical laboratories, and as research work had already been done by the Mining Department of McGill University on a number of western coals, Dr. Low invited Dr. Porter, the head of that department, to undertake the larger investigation. This proposal was approved by the University governors, and Dr. Porter was authorized to carry out the tests in the University laboratories, without charge; on the understanding that the Government would pay for such apparatus as might be required to supplement the existing equipment, and to make good all additions to the salaries, wages, and supplies accounts, rendered necessary by the investigation. At the request of Dr. Low, also, the Intercolonial and Canadian Pacific railways very generously agreed to haul the material—amounting to many hundreds of tons— free of charge.

Shortly after the commencement of the investigation the Dominion Department of Mines was created, under the Hon. William Templeman, as Minister of Mines, and Dr. A. P. Low, as Deputy Minister; and the investigation, together with all matters relating to economic minerals, was transferred from the Geological Survey to the Mines Branch, under the Directorship of Dr. Eugene Haanel. The original arrangement was, however, in all other respects, continued without change.

From the beginning it was intended to confine the investigation to the coals and lignites of the Dominion; and the following points were covered by the scheme:—

Sec.   I.—General organization and administration.

Sec.   II.—Preparation of a general summary report on Canada's coal fields and coal mines.

Sec. III.—Sampling in the field.

Sec.   IV.—Crushing the samples and preparing them for treatment.

Sec.   V.—Washing and mechanical purification.

Sec.   VI.—Coking trials.

Sec. VII.—Steam boiler trials.

Sec. VIII.—Producer, and gas engine trials.

Sec.   IX.—Chemical laboratory work, and miscellaneous investigations.

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TECHNICAL STAFF.

The technical staff engaged in the investigation, comprised:—

(1). J. B. Porter, E.M., Ph.D., D.Sc., Professor of Mining Engineering, McGill University—Responsible for the organization and general direction of the investigation, and directly in charge of Sections I, IV, and V, and VI (in part).

(2). R. J. Durley, B.Sc., Ma.E., Professor of Mechanical Engineering, McGill University— In charge of Sections VII and VIII.

(3). Théo. C. Denis, B.Sc., Mines Branch, Department of Mines, Ottawa—In charge of Sections II and III (in part).

(4). Edgar Stansfield, M.Sc., Chief Chemist—In charge of Section IX, and Sections III and VI (in part).

(5). H. F. Strangways, M.Sc., Dawson Fellow in Mining, McGill University—Assistant in Sections IV and V 1907.

(6). H. G. Carmichael, M.Sc., Dawson Fellow in Mining, McGill University— Assistant in Sections IV and V 1908.

(7). E. B. Rider, B.Sc., Demonstrator in Mining, McGill University —Assistant in Sections IV and V 1909-10.

(8). Chas. Landry, Chief Mechanic of Mining Department, McGill University—Foreman in Sections IV and V.

(9). J. W. Hayward, M.Sc., Assistant Professor of Mechanical Engineering, McGill University—Assistant in charge of Section VII 1907, and preliminary work in Section VIII.

(10). J. Blizard, B.Sc., Lecturer on Mechanical Engineering, McGill University—Assistant in charge of Section VII 1908, and Assistant in Section VIII.

(11). D. W. Munn, M.A., B.Sc., Demonstrator in Mechanical Engineering ,McGill University—Assistant in Sections VII and VIII.

(12). G. L. Guillet, M.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VII.

(13) G. Killam, M.A., B.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VIII.

(14). J. S. Cameron, B.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VIII.

(15). A. Balmfirth, Superintendent of McGill University Power House—Foreman in Section VII.

(16). J. Gardner, Foreman in Section VIII.

(17). J. Hoult, Fireman in all tests of Section VII.

(18). J. H. H. Nicolls, B.Sc., Assistant Chemist—Assistant in Section IX 1908, 1909.

(19). R. T. Mohan, B.Sc., Assistant Chemist—Assistant in Section IX 1908.

(20). P. H. Elliott, M.Sc., Assistant Chemist—Assistant in Section IX 1908.

(21). E. J. Conway, B.Sc., Assistant Chemist—Assistant in Section IX 1908.

(22). W. B. Campbell, Assistant Chemist—Assistant in Section IX 1909.

(23). R. S. Boehner, M.Sc., Demonstrator in Chemistry, McGill University—Assistant in Section IX 1908, 1909.

(24). H. Hartley, B.Sc., Assistant Chemist—Assistant in Section IX 1909.

(25). W. B. Meldrum, B.Sc., of the Department of Chemistry, McGill University—Assistant in Section VI 1909.

(26). H. H. Gray, B.Sc., Demonstrator in Metallurgy, McGill University—Assistant in Section VI 1909.

(27). H. G. Morrison, B.Sc., Assistant Chemist—Assistant in Section IX, 1909, 1910.

There were also a number of machinists, mechanics, and labourers, engaged more or less continuously in the several sections.

In addition to the persons above named, the following members of the University staff very materially aided in the progress of the work by giving occasional assistance and advice:—

Alfred Stansfield, D.Sc., Professor of Metallurgy.

H. T. Barnes, D.Sc., Professor of Physics.

Acknowledgment is also due to the Governors of McGill University, and to W. Peterson, C.M.G., Principal; F. D. Adams, F. R. S., Dean; W. Vaughan, Esq., Secretary; S. R. Burrell, Esq., Chief Accountant, and many others.

LABORATORIES.

The laboratories of the Mining and Mechanical Departments of McGill University, in which the tests were made, were built and equipped some few years ago on a scale unequalled at the time in North America, the buildings and apparatus for the Ore Dressing Department alone costing over $150,000, and the Steam Laboratory an almost equal sum. This equipment needed very little augmentation in respect of sampling, crushing, coal washing, steam boiler tests, and chemical analysis; although a number of minor pieces of apparatus had to be purchased, such as extra calorimeters, pyrometers, thermometers, etc., etc.

In the matter of producer and gas engine tests, larger expenditure was necessary, as the University equipment was on too small a scale for the extensive tests contemplated. An addition 25×70 was, therefore, built to the Ore Dressing Laboratory, and equipped with a complete plant of the most modern type, the cost for building and plant being approximately $12,000. A detailed description of this plant, with cuts of the apparatus, etc., will be found in Vol. II, Part VIII of the report, and similar descriptions of the apparatus used in the other parts of the investigation will be found in the other parts.

THE INVESTIGATION.

Sampling in the field.

Sixty-three separate mines or seams were specially sampled for the investigation. The work of sampling was always done by a responsible member of the technical staff, and every precaution was taken to ensure reliability. The general rules governing this sampling and the detailed descriptions of the work of sampling at the several mines are fully stated in Vol. I, Part III.

A list of the samples arranged in geographical order is given in the table of contents of each volume of the appendices III, IV, and V, and is printed in the text of the Report proper, Vol. I, pp. 8 to 11 and Vol. II, pp. 181 to 184; also in this Vol., pp. 17 to 20.

Crushing and Sampling in the Laboratory.

The main samples on their arrival at the testing plant at McGill University were all crushed to go through a 2″ screen, mixed thoroughly on a large granolithic sampling floor, sampled for the chemist, etc., and finally resacked, sealed, and sent to a dry room for storage while awaiting test.

The methods of sampling are stated in detail in Vol. I, Part IV.

The smaller subsidiary samples were sent directly to the chemical laboratory, where they were stored in sealed vessels until required.

Mechanical Purification.

Each main sample was experimentally treated in the laboratory with heavy solutions, and the fractions analysed with a view to determining the probable results of washing. In all cases where these preliminary tests gave favourable results, a large lot was treated in the coal washing plant of the University, and this work was checked by a further series of tests with heavy solutions.

It would, of course, be possible in a laboratory to do extremely thorough washing at an expense disproportionate to the value of the coal; but this was not attempted, the aim being to reproduce commercial conditions. From comparative tests made between laboratory work and coal washing in standard plants, it is evident that this end has been attained, and the tests as carried on may be taken in a broad way to represent average commercial work.

The whole subject of coal washing as well as testing is dealt with in Vol. I, Part V, and the results of all the trials are presented in a series of summary tables. The detailed results of each test are given in Volume III.

Coking Trials.

The determination as to whether or not any particular coal will make a good coke is of great practical importance, and until recently it has been considered impossible without first conducting a series of oven trials on a large and costly scale. Even a single full sized experimental oven is unsatisfactory for such work, as its operation differs much from that of an oven surrounded by its fellows; and as a result the only safe course has been to send a very considerable quantity of each coal to be tested to a bank of ovens and to test it under standard conditions, repeating the operation if necessary with different coking periods until a definite conclusion can be reached.

It was obviously impossible to carry out complete tests of the above character on all of the fifty odd coals in the series under consideration, and, therefore, an extended investigation was undertaken at the coking plant of the Dominion Iron and Steel Co. at Sydney, N.S., with a view to developing some reliable method of working on a small scale. These experiments, supplemented by tests in various types of oven in different places in Canada, finally led to a satisfactory conclusion, and it is now possible to test coals in lots of say 50 pounds, the resultant cokes being in every way similar to those produced in commercial ovens and in most cases indistinguishable from them.

The method in brief is as follows: the sample of coal, which should be as fresh as possible, is crushed, washed if necessary, and slightly moistened in some cases, and thus brought to exactly the conditions in which it would normally go to the oven. It is then put in rectangular boxes of heavy sheet iron, each holding say 50 pounds. These boxes are freely perforated to permit of the escape of gas, but the perforations are blanked with paper to prevent the egress or ingress of coal. The boxes are weighed and placed in an oven which is being charged, and become, in fact, a part of its regular charge and are coked under perfectly normal conditions. On the withdrawal of the charge, the boxes are quenched as promptly yet as lightly as possible, and are then dried and weighed before being opened.

In addition to the straightforward trials to determine whether the several coals would or would not coke, a series of tests was made to determine the effect of moistening, compressing, etc., and of different temperatures and durations of the coking period.

A method had to be devised also to determine the strength of the cokes produced. Mere crushing tests do not suffice, and it was finally decided to adopt a standard method of testing in a tumbler to determine the losses in handling, and of crushing to a fixed pressure in bulk to determine strength in coke bins and furnaces.

Another series of tests was made to determine the effect of weathering on coal before using it for coke production. Some coals will coke only when quite fresh; others will coke, but not so well, when stale; still others

do not seem to be affected even by comparatively long exposure to the air. The whole matter is somewhat obscure and chemical analysis does not cast as much light on it as one could wish.

The subject of coking, as well as the testing of coking qualities, is dealt with in Vol. I, Part VI, and the results of all of the main trials are presented in a series of summary tables. The detailed results of the tests and the full records of a number of subsidiary tests are given in Appendix IV of the present volume.

Boiler Trials.

The boiler trials were conducted in the boiler testing room of the University, the method used being as far as possible in accordance with standard practice.

The boiler, which is a Babcock and Wilcox, rated at 60 H.P., was thoroughly cleaned and tested before the trials were commenced, and standardizing tests were run with Georges Creek coal. The series included 72 trials, each of which lasted at least ten hours.

The methods employed in conducting the trials are fully detailed in Vol. II, Part VII, and this part also contains a general discussion of the use of coal for steam raising, and a tabular summary of the whole series of trials.

Full notes of each of these trials are published in Vol. IV, Appendix II, followed by the summary record above referred to reprinted from Vol. II.

Producer Trials.

The producer trials were made in a special laboratory erected and equipped for the purpose at McGill University. Several producers were tested, but the standard trials were carried out in a special down-draught producer rated at 40 H.P.

The trials lasted at least 24 hours, and were checked by longer runs— one of 10 days.

The methods employed in conducting the trials are fully set forth in Vol. II, Part VIII, and the results of the trials are presented in tabular form. This Part also contains a discussion of general questions of the use of producers and gas engines for the generation of power. The detailed results of the trials are contained in Vol. V, Appendix III.

Chemical Laboratory.

The work that had to be done in the Chemical Laboratory was very considerable. Methods and apparatus had to be devised, tested, and standardized, and all materials, whether raw, intermediate, or final products,

had to be analysed. No count of the total number of analyses made has ever been made, but a mere enumeration of the different materials analysed and of the different analyses, determinations, and investigations carried out will give some idea of the extent of the work done.

MATERIALS ANALYSED.

Coal Samples—main, mine, weathering, boiler trial, gas producer tests, coking tests, final washed coal, separate products of washery, specific gravity tests, screen analyses, etc. *Coke samples* from coking tests: *gas samples* from boiler trials, gas producer tests and coking tests: *ash samples* from boiler trials, gas producer tests, and laboratory combustion of raw and washed coal.

CHEMICAL DETERMINATIONS MADE.

Carbon, hydrogen, oxygen, sulphur, nitrogen, moisture, ash, volatile matter, fixed carbon, combustible matter, carbon dioxide, carbon monoxide, ethylene, methane.

PHYSICAL DETERMINATIONS MADE.

Fusion temperature of ashes, specific gravity, porosity and strength of cokes, calorific values of solid and gaseous fuels.

SPECIAL INVESTIGATIONS.

Special investigations have been made on the determination of sulphur in coal, determination of volatile matter in coal and coke, solubility of coal in water, determination of physical values of coke, weathering of coal, etc. An investigation is also being carried out on the spontaneous combustion of coal in storage, but as this is in addition to the original research and is being supported by private contribution, it is intended to insert only a preliminary article here and to submit the full results in a special supplementary report to be published as soon as possible after the present volume.

The regular methods of analysis adopted in the routine tests are described and discussed in Vol. II, Part IX, in connexion with a series of tables giving a summary of the analyses of all of the coal samples.

A large amount of additional matter is presented in Appendix V of the present volume, the separate papers including discussions of some of the special investigations preliminary to the adoption of the standard methods and detailed descriptions of several subsidiary investigations.

THE REPORT.

It will be seen from the above description of the investigation that an attempt has been made to cover a large field, and yet to do the work in great detail. As a result of this, a very large amount of information has been gathered; but much of it is so highly technical as to be only of interest to specialists, hence it has been thought best to divide the Report —which comprises six volumes—into two main sections, of two and four volumes respectively.

In the first section there are separate chapters, or parts, dealing with each of the seven divisions of the investigation outlined in the last few pages. Each of these parts begins with an introduction in which the subject of the division is dealt with in a general way, followed by a more or less extended description and discussion of the experimental work attempted; and concluding with a carefully tabulated summary of all of the tests in that division.

Preceding the technical reports referred to above there are two important chapters, the first being an introduction dealing with the investigation as a whole, and the second being a very full descriptive paper on the history, geology, and present commercial development of the coal fields and coal mines of Canada, from the pen of Mr. Théo. C. Denis— a member of the permanent staff of the Mines Branch of the Department of Mines. This part of the Report, which is profusely illustrated with maps and photographs, differs from the remainder in that its matter is largely drawn from previous publications of the Geological Survey and other sources, but it possesses great value as an introduction to the somewhat technical reports which follow, and is of importance, on its own account, as the most complete work yet written on the coal fields of the Dominion.

The first two volumes of the Report, comprising Parts I to IX inclusive, may, therefore, be considered as complete in themselves, and it is hoped that they will prove of value not only as contributions to the technological literature on coal, but also as a source of useful and timely information to the general public, on the coal resources of the Dominion and on the best methods of utilizing these resources.

The remaining four volumes, III, IV, V, and VI,[1] are given up exclusively to tabulated records and details of the tests summarized in Volumes I and II, to which they thus become highly technical appendices.

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[1] Inasmuch as Mr. Edgar Stansfield became a member of the permanent staff of the Mines Branch, and hence had new duties to perform prior to the completion of the reports on the sections with which he was connected, it was necessary for him to write nearly the whole of Part IX and of Vol. VI in his private time; and, on account of Civil Service regulations, without remuneration. This has resulted, unavoidably, in the omission from Vol. VI of any account of several minor investigations and the abbreviation of certain parts.

LIST OF COALS TESTED.

Sydney Coal Field, Cape Breton Co., N.S.

    No. 50[1]—Gowrie seam, North Atlantic Collieries, Ltd., Port Morien, N.S.

    No. 36—Dominion No. 7. Hub seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 35—Dominion No. 9. Harbour seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 35 SP.—Dominion No. 5. Phalen seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 38—Dominion No. 1. Phalen seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 37—Dominion No. 10. Emery seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 39—Dominion No. 12. Lingan seam, Dominion Coal Co., Ltd., Glace Bay, N.S.

    No. 13—No. 1 Colliery, Nova Scotia Steel and Coal Co., Ltd., Sydney Mines, N.S.

    No. 12—No. 3 Colliery, Nova Scotia Steel and Coal Co., Ltd., Sydney Mines, N.S.

Inverness Coal Field, Inverness Co., N.S.

    No. 14—Inverness Colliery, Inverness Railway and Coal Co., Inverness, N.S.

    No. 15—Port Hood Colliery, Richmond Railway Coal Co., Ltd., Port Hood, N.S.

Pictou Coal Field, Pictou Co., N.S.

    No. 4—Six foot seam, Vale Colliery, Acadia Coal Co., Ltd., New Glasgow, N.S.

    No. 16—Foord seam, Allan Shaft Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.

    No. 1—Third seam, Albion Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.

    No. 2—Cage Pit seam, Albion Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.

    No. 8—Main seam, Acadia Colliery, Acadia Coal Co., Ltd., Westville, N.S.

    No. 3—Main seam, Drummond Colliery, Intercolonial Coal Mining Co., Ltd., Westville, N.S.

Springhill Coal Field, Cumberland Co., N.S.

    No. 49—No. 1 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

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[1] The distinguishing numbers of the coal samples were arbitrarily assigned at the time, and have been retained for convenient reference. They have no other significance.

No. 5—No. 2 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

No. 6—No. 3 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

Joggins-Chignecto Coal Field, Cumberland Co., N.S.

No. 7—Chignecto Colliery, Maritime Coal, Railway, and Power Co., Ltd., Chignecto, N. S.

No. 9—Minudie Colliery, Minudie Coal Co., Ltd., River Hebert, N.S.

No. 10—Joggins Colliery, Canada Coals and Railway Co., Ltd., Joggins, N.S.

Grand Lake Coal Field, Queens Co., N.B.

No. 11—King's Mine, G. H. King, Minto, N.B.

Souris Coal Field, Sask.

No. 40—Western Dominion Collieries, Ltd., Taylorton, Sask.

No. 41—Eureka Coal and Brick Co., Ltd., Estevan, Sask.

Edmonton Coal Field, Alta.

No. 46—Strathcona Coal Co., Ltd., Strathcona, Alta.

No. 42—Parkdale Coal Co., Ltd., Edmonton, Alta.

No. 45—Standard Coal Co., Edmonton, Alta.

Belly River Coal Field, Alta.

No. 43—Canada-West Coal Co., Ltd., Taber, Alta.

No. 44—Galt Colliery, Alberta Railway and Irrigation Co., Ltd., Lethbridge, Alta.

No. 47—Breckenridge and Lund Coal Co., Lundbreck, Alta.

Frank-Blairmore Coal Field, Alta.

No. 48—Seven Foot seam (No. 1 Byron), Leitch Collieries, Ltd., Passburg, Alta.

No. 32—Hillcrest Colliery, Hillcrest Coal and Coke Co., Ltd., Hillcrest, Alta.

No. 33—Bellevue Colliery, No. 1 seam, West Canadian Collieries Co., Ltd., Bellevue, Alta.

No. 28—Lille Colliery, No. 1 seam, West Canadian Collieries Co., Ltd., Lille, Alta.

No. 34—Denison Colliery, No. 2 seam, International Coal and Coke Co., Ltd., Coleman, Alta.

No. 34 SP.—Denison Colliery, No. 4 seam, International Coal and Coke Co., Ltd., Coleman, Alta.

Crowsnest Coal Field, B.C.

No. 31—No. 3 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.

No. 30—No. 7 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.

No. 29—No. 8 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.

No. 51—No. 2 seam south, Hosmer Mines, Ltd., Hosmer, B.C.

No. 52—No. 6 seam south, Hosmer Mines, Ltd., Hosmer, B.C.

No. 53—No. 8 seam south, Hosmer Mines, Ltd., Hosmer, B.C.

No. 27—No. 2 mine, Coal Creek, Crowsnest Pass Coal Co., Ltd., Fernie, B.C.

No. 26—No. 5 mine, Coal Creek, Crowsnest Pass Coal Co., Ltd., Fernie, B.C.

Cascade Coal Field, Alta.

No. 25—No. 1 or Old mine, H. W. McNeil Co., Ltd., Canmore, Alta.

No. 23—Pea size, Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.

No. 23 SP.—Buckwheat size, Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.

No. 23 M.—Mixed, 23 and 23 SP., Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.

No. 24—Briquettes from Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.

Similkameen Coal Field, B.C.

No. Ex. 1—No. 1 opening, Granite Creek, B.C.

No. Ex. 2—No. 2 opening, Granite Creek, B.C.

No. Ex. 3—No. 4 opening, Granite Creek, B.C.

Nicola Valley Coal Field, B.C.

No. 22—Jewel seam, No. 1 mine, Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.

No. 22 SP.—Rat Hole seam, No. 2 mine, Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.

No. 22 M.—Mixture of 22 and 22 SP., Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.

Whitehorse Coal Field, Yukon Territory.

No. Ex. 31—Upper seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.

No. Ex. 32—Middle seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.

No. Ex. 33—Lower seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.

Nanaimo-Comox Coal Field, Vancouver Island, B.C.

No. 20—Wellington seam, Wellington - Extension Colliery, Wellington Colliery Co., Ltd., Extension, B.C.

No. 18—Upper seam, No. 1 mine, Western Fuel Co., Ltd., Nanaimo, B.C.

No. 17—Lower seam, No. 1 mine, Western Fuel Co., Ltd., Nanaimo, B.C.

No. 21—Lower seam, No. 4 mine, Comox Colliery, Wellington Colliery Co., Ltd., Cumberland, B.C.

No. 21 SP.—Lower seam, No. 7 mine, Comox Colliery, Wellington Colliery Co., Ltd., Cumberland, B.C.

No. 21 M.—Mixture of Nos. 4 and 7 Mines, Comox Colliery, Wellington Colliery Co., Ltd., Cumberland, B.C.

Alert Bay Coal Field, Vancouver Island, B.C.

No. Ex. 34—Suquash mine, Pacific Coast Coal Co., Alert bay, Vancouver island, B.C.

MANUFACTURE AND TESTING OF COKE

BY

EDGAR STANSFIELD and J. B. PORTER.

MANUFACTURE AND TESTING OF COKE.

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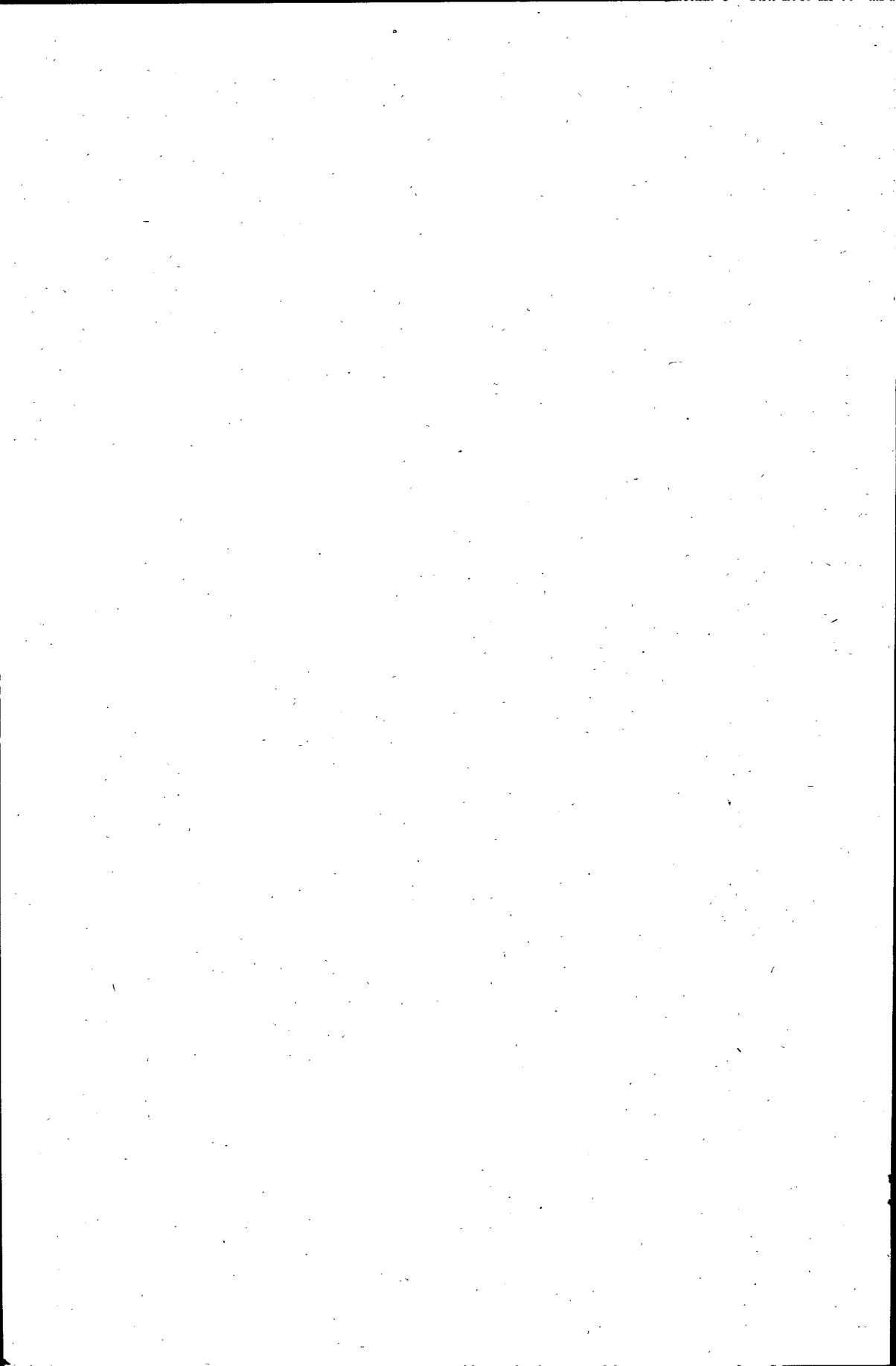
EDGAR STANSFIELD and J. B. PORTER.

DETAILED RECORDS OF COKING TESTS.

An account is given of the methods employed in the coking tests in Vol. I, pp. 213-219, and of the preliminary tests, made before the methods were decided upon, in Vol. I, pp. 219-222. The following are notes made during the course of the tests, and may be studied with advantage in connexion with the summary records of the tests which will be found in Vol. I, Tables XXIX-XLIV inclusive.

After a test box of coal had been coked, quenched, and dried, it was in every case opened and examined by the writer, with occasional help from the coke oven staff experts, and notes made as to the character of the coke and any special points observed. In the case of cokes made at Lille and Coleman, this examination was done at McGill; in all other cases it was done at the coke ovens—such notes are marked (a).

A typical sample of the coke was then taken, which was afterwards, at McGill, divided into four similar samples of about three or four pounds weight (required for different purposes). This work was done by three members of the staff, who made notes which are marked (b). One of the above four samples was placed in a tray, and the trays were arranged for inspection according to the geographical order of the source of the coal. These tray samples were then carefully examined and compared and notes made by Dr. J. B. Porter, assisted by E. Stansfield, or by E. Stansfield, assisted by W. B. Meldrum. These notes, which are marked (c), usually took the form of classifying the cokes according to the following scheme:—

A = good commercial coke—subdivided +A, A, −A.
B = poor commercial coke—subdivided +B, B, −B.
C = an agglomerate, not commercial coke—subdivided +C, C, −C.
D = non-agglomerating.

The first inspection had the great advantage that the whole quantity of coke produced was under inspection, and its behaviour whilst it was being broken up for removal from the box gave considerable insight into its character. The tests in the Sydney district lasted over a month, and the tests in the Crowsnest district were unavoidably delayed until over six months later, so that it was impossible to maintain a uniform standard of criticism—a fair coke among a number of poor cokes would inevitably be regarded more favourably than the same coke, had it been examined about the same time as a number of good ones.

TABLE I

AVERAGES OF ANALYSES OF COKES FROM FRESH COALS

		Otto-Hoffman at Sydney				Bernard at Sydney Mines		Bernard at Lille		Beehive at Coleman	
1.	Ovens in which cokes were made...........										
2.	Coal field............................	Sydney, N.S.	Pictou, N.S.	Spring-hill, N.S.	Similka-meen, B.C.	Sydney, N.S.	Joggins-Chignec-to, N.S.	Frank-Blair-more, Alta.	Crows-nest, B.C.	Frank-Blair-more, Alta.	Crows-nest, B.C.
3.	Number of samples included in average.....	5	4	3	2	4	1	6	6*	2	2
	Chemical analysis of dry coke										
4.	Fixed carbon (FC)....................%	87·5	86·4	92·1	....	84·1	78·0	76·9	83·4	78·6	86·3
5.	Volatile matter (VM)..................%	1·5	0·6	1·5	....	2·6	2·4	0·9	0·9	1·9	1·3
6.	Ash.................................%	11·0	13·0	6·4	20·9	13·3	19·6	22·2	15·7	19·5	12·4
7.	Sulphur.............................%	2·9	1·3	0·7	....	1·7	5·5	....	....	....	....
8.	Duration of coking...............hours	47	48	40	41	48	48	48	48	74	74
9.	Yield of dry coke from dry coal..........%	70·8	75·3	71·6	....	....	....	76·9	77·3	78·5	78·0
10.	Theoretical yield (FC + ash of coals coked)%	63·8	71·7	67·0	67·7	64·3	61·6	73·8	75·2	73·6	75·0
11.	Apparent specific gravity................	0·91	1·01	0·88	1·03	0·92	0·86	1·24	1·09	1·20	1·10
12.	Real specific gravity....................	1·90	1·94	1·81	1·78	1·76	1·80	1·90	1·88	1·90	1·87
13.	Percentage cell space or porosity (P).....%	52·0	47·9	51·4	42·1	47·7	52·0	34·7	42·0	36·8	41·2
14.	Relative crushing strength (S)............	0·81	0·98	0·97	0·81	0·77	0·89	0·68	0·88	0·74	0·94
15.	Physical value (P × S)...................	42·4	47·3	49·9	34·2	36·6	46·2	23·8	36·6	27·0	38·5
16.	Physical value (P × S²).................	34·8	46·6	48·3	28·4	28·6	41·1	16·3	32·1	19·8	35·8

* One very bad sample omitted.

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The second inspection was of a smaller quantity of coke, but had this advantage that all the cokes made in each district were examined about the same time and the hardness, etc., of the coke could be noted when the pieces were broken with a hammer.

At the third inspection, a still smaller sample was available and this could not be broken up, but all the samples from both districts were spread out at once for inspection, and as from time to time trays under inspection were taken back and compared with those already judged, it was possible to maintain a very constant standard of classification.

Where the notes included comparisons between cokes produced from coals from different collieries it has been thought better to omit such comparisons.

AVERAGES OF ANALYSES OF COKES FROM FRESH COALS.

For purposes of ready comparison, etc., average values have been calculated for the chemical and physical properties of the different cokes, classified under the coal fields from which the coals came, and according to the ovens in which the cokes were made. In calculating these averages, only those cokes are considered which were made from coals that had been mined less than one month before they were coked; only one coal had been mined more than half a month. These averages are shown in Table I.

Line 3 of the table gives the number of samples included in each average analysis; it will be fairly obvious that it is not possible to consider the difference, for example, between the average coke from Sydney coals coked in Otto-Hoffman ovens, and the average coke from Sydney coals coked in Bernard ovens, as due simply to the difference of oven, since different coals were coked in the two places.

COKING TESTS MADE BY MR. T. C. DENIS IN THE OTTO-HOFFMAN OVENS AT SYDNEY, JUNE 20-22, 1908.

Metal drums were used for these tests about 18″ long by 8½″ diameter; all coked for 41 hours.

Coal Ex. I, No. 1 Opening, Granite Creek, B.C. 44 lbs. dry coal, coked dry.

    (a) Non-coking.

Coal Ex. 201, No. 1 Opening, Granite Creek, washed coal. 44 lbs. dry coal, coked dry.

    (a) Non-coking.

Coal Ex. 2, No. 2 Opening, Granite Creek. 44 lbs. dry coal, coked dry.

    (a) Fair coke.

Coal Ex. 202, No. 2 Opening, Granite Creek, washed coal. 44 lbs. dry coal, coked dry.

    (a) Excellent coke.

Coal Ex. 3, No. 4 Opening, Granite Creek.   44 lbs. dry coal, coked dry.

  (a)   Decidedly non-coking.

Coal Ex. 203, No. 4 Opening, Granite Creek, washed coal.   44 lbs. dry coal, coked dry.

  (a)   Decidedly non-coking.

  Coal 22, Jewel seam, Middlesboro colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.   44 lbs. dry coal, coked dry.

  (a)   Non-coking.

The above drums were divided between two ovens, in each of which was also coked a drum containing about 55 pounds of moist, washed, Dominion Coal Co.'s coal, as charged into the ovens.   The comparisons between these cokes and samples of coke produced at the same time in the open oven are given in Vol. I, pp. 219-220.

COKING TESTS MADE IN BATTERY IX OF THE OTTO-HOFFMAN OVENS OF THE DOMINION IRON AND STEEL CO., AT SYDNEY, C.B., DECEMBER 1908 AND JANUARY 1909.

Preliminary Tests—Age of Coal.

Three coals were chosen for this test; the boxes containing them were charged into Oven 18, Battery IX, on Dec. 22, 1908, the oven was pushed 41 hours later.   The boxes came out in good condition, the lids had sunk 1 or 2 inches.

Box 1, fresh Phalen seam coal from Dominion Coal Co., washed, as charged into ovens at the time.   Coke C 1.

  Weight of moist coal, $38\frac{1}{2}$ lbs.

  (a)   Coke was excellent, very little small coke at the top, regular fracture, some larger cells in the centre but no sponge.

  (b)   Good ring, minimum of breeze, if anything slightly stronger than the next sample, also on the whole slightly cleaner in appearance, although there was more sooty coke.

Box 2.   Coal 38, about 6 months old, Phalen seam coal from Dominion Coal Co., No. 1 colliery.   Coke C1/38.

  Weight of dry coal, $37\frac{1}{2}$ lbs; of moist coal, 43 lbs; water in coal as coked $= 12 \cdot 8$ per cent.

  (a)   Coke was excellent, very little small coke on top.   A good piece of this coke, when shown to an expert, in comparison with a good piece of the previous sample, was with some hesitation picked as being from the older coal.   The fact that this coal was unwashed might almost account for any difference.

  (b)   Decidedly good hard coke.

Box 3, Coal 12, about $17\frac{1}{2}$ month's old coal from the No. 3 pit of the Nova Scotia Steel & Coal Co.   Coke C1/12.

Weight of dry coal, $36\frac{1}{2}$ lbs.; of moist coal, 41 lbs.; water in coal as coked = 11 per cent.

(a) Coke was quite good at the bottom, although even here not so good as in boxes 1 and 2; at the top of the box there was a layer, 2″ or 3″ thick, of very poor coke in which some of the original pieces of coal could be seen. A good piece of this coke was immediately detected as inferior to the two previous samples.

(b) Fair coke, breaks up rather easily.

The choice of coals for this test was unavoidably unsatisfactory as no strictly comparable coals of different ages were available; the fresh coal was washed and the two older coals were not; moreover, it was learned later that coal 12 is not regarded as a very good coking coal, even when fresh. The above was fortunately of little moment, as the verdict arrived at—that the coking quality of coal, even when stored carefully in sacks, does deteriorate somewhat with age, although not as much as is sometimes supposed—was confirmed by later tests on comparable coals. It was, however, shown that different coals varied very much in their susceptibility to aging.

Preliminary Tests—Time of Coking.

Boxes were filled as uniformly as possible with moist washed coal such as was being charged into the ovens at the time. This was Phalen seam coal from the Dominion Coal Co., washed at the washery of the Dominion Iron & Steel Co.; it is afterwards referred to as D.I. & S. Co. coal. These boxes were charged into different ovens where they were coked for different lengths of time. The 41 hour coke and the two 48 hour cokes were tests made primarily for other purposes, but as they are strictly comparable with the rest, they are included to complete the series. Battery X was off for repairs at this time, which was said to reduce the draught and heat of Battery IX. Battery X went into commission again about the New Year.

30 Hour coke, C 11. Charged into oven, Dec. 28, 1908.
Weight of moist coal, 43 lbs.

This sample was the result of an attempt to make 24 hour coke. The box was charged into an oven, into which less coal than usual was subsequently introduced, but even so it was not found possible to push the oven after 24 hours, as a large quantity of volatile matter was still left in the coal. The doors were left loose and the oven pushed six hours later. Air could get in past the doors in the last period, and the resulting combustion of the coke would probably produce an unusually hot oven.

(a) Normal good coke in appearance.

36 Hour Coke, C 12. Charged into oven, Dec. 26.
Weight of moist coal, 45 lbs.

(a) Normal good coke in appearance.

41 Hour Coke, C 1. Charged into oven, Dec. 22.
Weight of moist coal, $38\frac{1}{2}$ lbs.

(a) Coke was excellent, very little small coke at the top, regular fracture, some larger cells in the centre but no sponge.

48 Hour Coke, C 5. Charged into oven, Dec. 23.

Weight of moist coal, $41\frac{1}{2}$ lbs.

(a) Good coke with very little small.

48 Hour Coke, C 7. Charged into oven, Dec. 24.

Weight of moist coal, $43\frac{1}{2}$ lbs.

(a) Quite good coke.

60 Hour Coke, C 13. Charged into oven, Dec. 29.

Weight of moist coal, 43 lbs.

(a) Good, silvery grey coke, probably better than ordinary, but hardly as good as the 72 hour coke.

72 Hour Coke, C 14. Charged into oven, Dec. 23.

Weight of moist coke, $44\frac{1}{2}$ lbs.

(a) Excellent silvery grey coke, the best coke produced in tests made up to this time.

In general, (a) the cokes were good from all the tests but improved with the time. The 72 hour coke was the best produced up to then, and the 60 hour not much worse.

(b) Samples C11-C14 classified by ring and appearance were placed in the correct order; classified by sound alone, C12 was placed too high. The longer time of coking brightens and hardens the coke.

Preliminary Tests—Position in Oven.

Four boxes were filled as usual with D.I. & S. Co. coal; three of these were fastened to three platforms of a rough lumber frame, which was then pushed into an empty oven, and the fourth box pushed along the floor of the oven to the foot of the frame. In this way one box was resting on the floor of the oven, the others being supported on successive steps of $1'-4''$ in height. There was an unexpected delay of nearly five minutes in charging coal into the oven, during which time the frame burned fiercely. The latter, however, held the boxes up until they were supported by the coal charged into the oven, as the boxes still maintained their original relative positions when the coke was pushed, although they had sunk with the contraction of the charge during coking. The boxes were charged into the oven on Dec. 24, and coked for forty-eight hours.

Box on floor of oven. Coke C7.

Weight of moist coal, $43\frac{1}{2}$ lbs. Yield of dry coke from dry coal $=70\cdot6\%$.

Box supported $1'-4''$ above floor. Coke C8.

Weight of moist coal, $43\frac{1}{2}$ lbs. Yield of dry coke from dry coal $=70\cdot4\%$.

Box supported $2'-8''$ above floor. Coke C9.

Weight of moist coal, $42\frac{1}{2}$ lbs. Yield of dry coke from dry coal $=70\cdot8\%$.

Box supported 4'-0" above floor. · Coke C10.

Weight of moist coal, 43½ lbs. Yield of dry coke from dry coal = 70·2%. This top box was not entirely protected by coal, one of the top corners of the box being burned away. The coke did not appear to be burned.

(a) The coke in all four boxes was quite good, but samples C7 and C8 were perceptibly better than C9 and C10. There was hardly any perceptible difference between C7 and C8, one piece of C7 looking better than a piece of C8, and vice versa with other pieces. C9 was perhaps a trace better than C10, but not very noticeably so; The average of C7 and C8 was, however, noticeably better than the average of C9 and C10. The coke in the two lower boxes was firmer and harder than in the two upper ones; in the lower boxes there were also less open structure and less breeze.

(b) Previous opinion confirmed.

Preliminary Tests—Compression of Coal.

Two boxes 18″ × 16″ × 10″ were filled with D.I. & S. Co. coal; the first box was filled with as little compression of the coal as possible; the second box was filled, little by little, each layer being pressed well down before more coal was added. In each case the lid was rivetted in position so that it could not come out or get pressed farther in. The boxes were charged on Dec. 28, and coked for 48 hours.

Uncompressed Coal, Coke C15.

Weight of moist coal, 74½ lbs.

(a) Normal good coke.

Compressed Coal, Coke C16.

Weight of moist coal, 96½ lbs. This box was filled about ¾″ to 1″ fuller than the previous box.

(a) Normal good coke, but somewhat denser than usual. There was very little difference between the samples except that the compressed coal produced the denser coke.

(b) Coke C16 denser and brighter than C15.

Preliminary Tests—Moisture in Coal.

Three boxes were filled with D.I. & S. Co. coal, one dry, one ordinarily damp, and the third very wet; these were charged into an oven on Dec. 23, and coked for 48 hours.

Dry Coal, Coke C4.

Weight of moist coal, 47½ lbs; weight after drying, 42¼ lbs.; moisture in original moist coal, 10·5 per cent.

Moist coal was taken as usual and weighed in a box; the coal was then divided among 4 boxes and dried on an electric oven over night, and inside

it for about six hours the next day; the oven was supposed to keep at 110°C. The coal was then brought back to its original box and reweighed; a little dust would be lost and the coal was probably not absolutely dry.

(a) Good coke; but there was a good deal more small coke on the top of the box than was the case with the ordinary wet coal. The quality of coke at the bottom was not apparently different.

Ordinary wet coal, Coke C5.

Weight of moist coal, 41½ lbs. Probably about 10 per cent water.

(a) Good coke with very little small.

Very wet coal, Coke C6.

Weight of wet coal, 54 lbs.

This coal was taken from the top of one of the washery draining tanks just under a spout; it was rather smaller coal than usual, and as it was not very wet, water was poured into the box during the filling process and the coal stirred with a stick. The box was left to drain for half an hour before weighing. The result of the thorough wetting of the fine coal was that the coal settled down more compactly than usual into the box.

(a) The coke was more friable on the top and in the centre than C5, but not so much so as C4; the best coke in C6 was hardly as good as the best coke in C5. (Mr. Lucas preferred C6 to C5, presumably on account of its greater density).

(b) There is very little choice between C4, C5, and C6. C4 is the hardest and gives the best ring when hit; C5 contains more soot than C4, also it is not quite so strong; it is the dirtiest and yet the brightest in spots. C6 is very close to C5.

Preliminary Tests—Yield of Coke.

In order to compare the yields of coke obtained in box tests with those obtained in commercial practice, a sample of D.I. & S. Co. coal was dried for three days on an oil-cloth on a cool part of the boiler flue, weighed, moistened, put in a box, and coked in the usual way for 48 hours. Charged about January 7.

Weight of dry coal, 42 lbs.; water in coal as coked $7 \cdot 9\%$; yield of dry coke from dry coal, $72 \cdot 3\%$.

(a) Box came out in good condition; the coke was practically as usual, but possibly a trace more slaty matter visible.

Careful tests made some years before on a single oven showed 67% commercial coke and 2% breeze produced from dry, washed coal; this practice had been gradually improved until at the time the above test was made the yield was about 70% commercial coke and $1 \cdot 5\%$ breeze, or $71 \cdot 5\%$ in all, as compared with $72 \cdot 3\%$ in the box test.

Preliminary Tests—Comparison of Open Oven with Box Coke.

A sample of coke, C83, produced from D.I. & S. Co. coal in the usual way in an Otto-Hoffman oven, was taken to represent the average output of an oven.

(b)   Compared this coke with C1, which is the same coal coked for the same time, 41 hours, in a box.   More soot than in C1, but no more than in some other similar cokes; apparently less dense.

(c)   Open oven coke is a trifle duller and more porous on the average than box coke; this impression is possibly due to extra density of inch of skin next to the box.

Blending Tests.

A few blending tests were added to the regular coking tests in order to ascertain the possibility of converting anthracite or lignite screenings into a merchantable product, by means of coking, after blending with a good coking coal.

1 part coal 23M with 2 parts D.I. & S. Co. coal.

Coal 23M was an anthracite coal from the Bankhead Colliery, Alta.

16 lbs. of 23M and 35 lbs. of moist D.I. & S. Co. coal were mixed well together and moistened on an oil-cloth, then pressed down into a box and coked for 48 hours.

(a)   A fair commercial coke; the larger particles of anthracite still show; by using anthracite *dust*, very well mixed in, it should make a useful coke.

(b)   Breaks up rather easily, producing breeze.

(c)   Class B.

1 part coal 23M with 2 parts coal 31.

Coal 31 was from the No. 3 mine, Michel colliery, B.C.

16 lbs. of 23M and 32 lbs. of 31 were mixed, damped, boxed, and coked, as before.

(a)   A fair coke cementing together particles of unchanged anthracite.

(b)   Produces a good deal of breeze, no regular fracture.

(c)   Class—B.

2 parts coal 23M with 3 parts coal 26.

·Coal 26 was from No. 5 mine, Coal Creek, Fernie, B.C.

20 lbs. of 23M, crushed to pass a wire screen of 4 mesh to the inch, and 30 lbs. of 26 were treated as before.

(a)   Coal coked to a dry crumbly mass showing particles of original anthracite; probably of no commercial value.

(b)   Soft and friable, producing a lot of breeze.

(c)   Class+C.

1 part coal 25 with 2 parts coal 20.

Coal 25 was an anthracitic coal from the Old mine, Canmore, Alta., coal 20 was from the Wellington seam, Wellington-Extension Colliery, Vancouver island.

Took 16 lbs. of 25 and 32 lbs. of 20 and treated as before.

(a) Hardly a commercial coke; had only just coked and there was a lot of loose breeze, a lot of the particles not having fused at all.

(b) Friable coke, no regular cleavage.

(c) Class — B.

1 part coal 2040 with 2 parts coal 31.

Coal 2040 was a lignite from Taylorton, Sask., and coal 31 was from Michel, B.C.

Took 16 lbs. of 2040 and 32 lbs. of 31 and treated as before.

(a) Coke might possibly be of some commercial use; the particles of lignite were all there unchanged, but cemented into the body of the coke.

(b) Soft, friable, dull looking coke.

(c) Class — B.

Coking Tests of Regular Coals.

Coal 50.—North Atlantic Collieries, Port Morien, N.S., Gowrie seam. Coke C1/50. Age of coal when coked less than $\frac{1}{2}$ month.

Dry coal coked, $49\frac{3}{8}$ lbs. Water as coked, $8 \cdot 4\%$. Charged to oven, Jan. 17, 1909. Coked 40 hours.

(a) The coke was insufficiently quenched and showed signs of burning. Sound coke to top, on the whole fairly good quality, although breaking up rather easily. Washing the coal would make a great improvement.

(b) Open cellular coke; breaks up easily but without producing much breeze.

(c) Class — A.

Coal 36.—Dominion Coal Co., Glace Bay, N.S., Dominion No. 7, Hub seam.

Coke C1/36. Age of coal, under 7 months.

Dry coal coked, 48 lbs. Water in coal as coked, $9 \cdot 7\%$. Charged to oven, Jan. 14. Coked 48 hours.

(a) Box came out of oven in poor condition. Coke looks like coke from similar fresh coal, coke C1/2036, the only visible difference being that the coke from the older coal was more fragile and broke up into smaller pieces when it was taken out of the box.

(b) Very pretty, but not very strong coke; breaks into curved rods.

(c) Class + A. More fissured than coke from fresh coal.

Coal 2036.—Fresh sample of coal like 36.
Coke C1/2036.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, $47\frac{1}{2}$ lbs.   Water in coal as coked, 11·0%.   Coked with C1/36.

(a)   Coke shows fair shrinkage, good quality to top; is nice clean and bright, but like other cokes from D.C. Co.'s coals has a good deal of cross fracture, although this is, if anything, more conspicuous than usual with this coal.

(b)   Slightly brighter and stronger than C1/36, and does not break up into quite such small pieces.

(c)   Class + A.

Coal 35.—Harbour seam, Dominion No. 9.
Coke C1/35.   Age of coal, under 7 months.
Dry coal coked, 49 lbs.   Water in coal as coked, 7·8%.   Box charged to oven Jan. 14.   Coked 48 hours.

(a)   Box came out in bad condition and some coke was lost. Coke like that from similar fresh coal, C1/2035, only slightly less cellular; sound to top with regular cleavage but breaks up rather easily, owing to cross fractures.

(b)   Good hard coke.

(c)   Class A.

Coal 2035.—Fresh sample of coal like 35.
Coke C1/2035.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 48 lbs.   Water as coked, 10·3%.
Coked with C1/35.

(a)   The coke was fairly tight in the box.   Good coke, open cell structure, sound to top, regular cleavage, but rather smoky.

(b)   Not noticeably different from C1/35.

(c)   Class A.   Rather brighter and better than C1/35.

Coal 35 SP.   Phalen seam, Dominion No. 5.
Coke C1/35 SP.   Age of coal, under 7 months.
Dry coal coked, 47 lbs.   Water as coked, 7·6 per cent.   Charged Jan. 14, and coked for 48 hours.

(a)   Good sound coke to top of box.   Ordinary good coke in appearance, regular cleavage, but cross fractures cause the coke to break up somewhat.

(b)   Good strong coke.

(c)   Class A.   Slightly inferior to C1/35.

Coal 2035 SP.   Fresh sample of coal like 35 SP.
Coke C1/2035 SP.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 47 lbs.   Water as coked, 10·6%.   Coked with C1/35 SP.

(a)   Good sound coke to top of box.   Coke had regular cleavage, etc., like cokes C1/35 and C1/2035.

(b)   Not noticeably different from the coke from the older coal C1/35 SP.

(c)   Class A.   Very little difference between the cokes from the fresh and old coals, both slightly inferior to C 1/35.

Coal 38.   Phalen seam, Dominion No. 1.
Coke C1/38.   Age of coal, under 7 months.
Dry coal coked, 49 lbs.   Water as coked 8·5%.   Charged Jan. 17, and coked for 40 hours.

(a)   Good strong coke, sound to top of box, regular cleavage, breaks up into curved rods.   Rather smoky but otherwise looks very nice.

(b)   Decidedly strong coke; better than cokes made from same or similar fresh coal in the Bernard ovens at Sydney Mines, cokes, C3/38, and C3/2038.

(c)   Class + A.   Better than coke C 3/38.

Coal 37.   Emery seam, Dominion No. 10.
Coke C1/37.   Age of coal, under 7 months.
Dry coal coked, 48½ lbs.   Water as coked, 6·0%.   Charged Jan. 14, and coked for 48 hours.

(a)   Box came out in poor condition.   Very fair coke, possibly a trace dirtier and more fragile than coke from similar fresh coal, but the difference was too slight to be convincing.

(b)   Not very strong coke, contains a good deal of soot and visible slate.

(c)   Class+B.

Coal 2037.   Fresh sample of coal like 37.
Coke C1/2037.   Age of coal, under ½ month.
Dry coal coked, 46½ lbs.   Water as coked, 11·3%.   Coked with C1/37.

(a)   Very fair coke.   Not so pretty looking as coke C1/36, but does not break up so small.

(b)   Harder and less fragile than coke C1/37 and also shows less sooty matter.

(c)   Class −A.

Coal 39.   Lingan seam, Dominion No. 12.
Coke C1/39.   Age of coal, under 7 months.
Dry coal coked, 47½ lbs.   Water as coked, 10·6%.   Charged Jan. 17, and coked for 40 hours.

(a)   A good strong coke, sound to top, very much like C1/38; regular cleavage, markedly curved; a little smoked, but nice looking coke.

(b)   Bright, hard coke, but breaks up rather easily.

(c)   Class A.   Better coke than that from same coal coked in Bernard oven.

Coal 12. Nova Scotia Steel and Coal Co., Sydney Mines, N.S. No. 3 colliery.

Coke C1/12. Age of coal, under $17\frac{1}{2}$ months.

Dry coal coked, $36\frac{1}{2}$ lbs. Water as coked, $11\cdot0\%$. Charged Dec. 22, and coked for 41 hours.

(a) Coke was quite good at the bottom, but at the top of the box there was a layer 2″ or 3″ thick of very poor coke in which some of the original pieces of coal could be seen.

(b) Fair coke, breaks up rather easily.

(c) Class + B. Better coke than that from same coal coked in Bernard oven, C3/12.

Coal 14. Inverness Railway & Coal Co., Inverness colliery, N. S.

Coke C1/14. Age of coal, under $16\frac{1}{2}$ months.

Dry coal coked, $50\frac{1}{2}$ lbs. Water as coked, $8\cdot0\%$. Charged Jan. 4, and coked for 48 hours.

(a) Box was broken and half the contents lost. Had not coked although a little had caked.

Coal 15. Richmond Ry. Coal Co., Port Hood colliery, N. S.

Coke C1/15. Age of coal, under $16\frac{1}{2}$ months.

Dry coal coked, $47\frac{1}{2}$ lbs. Water as coked, $8\cdot4\%$. Charged Jan. 4, and coked for 48 hours.

(a) Not commercial coke; a lot of loose material at the top, the rest caked with a suspicion of coking close to the sides and bottom; sulphur visible at top.

(b) Friable agglomerate, showing a coking tendency at the outside.

(c) Class + C.

Coal 2004. Acadia Coal Co., Stellarton, N. S. A second sample from the Six Foot seam, Vale colliery.

Coke C1/2004. Age of coal, under $16\frac{1}{2}$ months.

Dry coal coked, $49\frac{1}{2}$ lbs. Water as coked, $8\cdot6\%$. Charged Jan. 3, and coked for 48 hours.

(a) Not commercial coke. Top layer loose, below that caked, but not more than 1″ or 2″ really coked.

(b) Friable agglomerate, showing a coking tendency at the outside.

(c) Class + C. No good.

Coal 16. Foord seam, Allan Shaft colliery.

Coke C1/16. Age of coal, under $16\frac{1}{2}$ months.

Dry coal coked, 47 lbs. Water as coked $10\cdot2\%$. Charged Jan. 10, and coked for 48 hours.

(a)   Excellent coke, sound to top of box; hardly so strikingly good as that from the fresh similar coal, C 1/2016; not so much shrinkage and harder to remove from the box.

(b)   Good, hard, strong coke.

(c)   Class A.   Good, strong coke, but still showing some original grains.

Coal 2016.   Fresh sample of coal like 16.
Coke C1/2016.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, $44\frac{1}{2}$ lbs.   Water as coked, $6 \cdot 6\%$.   Coked with C1/16.

(a)   A very excellent coke, sound to the top of the box; some shrinkage, resulting in very regular cleavage.

(b)   Excellent coke, slightly brighter and harder than C 1/16.

(c)   Class + A.   An exceptionally good coke.

Coal 1.   Third seam, Albion colliery.
Coke C1/1.   Age of coal, under 21 months.
Dry coal coked, 49 lbs.   Water as coked, $8 \cdot 2\%$.   Charged Jan. 3, and coked for 48 hours.

(a)   Not a commercial coke.   A lot of loose coal on the top, and the rest more caked than coked.

(b)   Soft, friable agglomerate, not really bonded.

(c)   Class C.   Merely agglomerate, no commercial value.

Coal 2.   Cage Pit seam, Albion colliery.
Coke C1/2.   Age of coal, under 21 months.
Dry coal coked, 46 lbs.   Water as coked, $7 \cdot 8\%$.   Charged Jan. 10, and coked for 48 hours.

(a)   Box came out badly damaged.   Coal had caked for about 3″ round sides and bottom, the rest was quite loose.

(b)   Dirty agglomerate, no true coke.

(c)   Class C.   Merely agglomerate, no commercial value.

Coal 2002.   Fresh sample of coal like 2.
Coke C1/2002.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 46 lbs.   Water as coked, $8 \cdot 2\%$.   Coked with C1/2.

(a)   Coke sound to top of box, not much shrinkage; coke slightly burned owing to insufficient quenching.   A good commercial coke fit for any blast furnace.

(b)   Good, hard, dense coke, regular fracture; shows no resemblance to the coke from the old coal from same seam, C1/2.

(c)   Class − A.   Good, strong, silvery coke; still, however, showing original fragments on outside.

Coal 8.   Main seam, Acadia colliery.
Coke C1/8.   Age of coal, under 21 months.
Dry coal coked, $48\frac{1}{2}$ lbs.   Water as coked, $8 \cdot 0\%$.   Charged Jan. 10, and coked for 48 hours.

(a) Box came out damaged but no coke lost. Coke firm to top, very little shrinkage; a good hard coke fit for anything.

(b) Good, hard, strong coke, very little inferior to coke from similar fresh coal except in lustre.

(c) Class—A. Good, strong coke. ·

Coal 2008. Fresh sample of coal like 8.
Coke C1/2008. Age of coal, under ½ month.
Dry coal coked, 47½ lbs. Water as coked, 6·7%. Coked with C1/8.

(a) Box came out slightly damaged, probably no coke lost. Little shrinkage; rather more loose at the top than usual, otherwise a good hard coke fit for anything.

(b) Dense, hard coke; first class quality.

(c) Class A. Slightly brighter and denser than coke C1/8.

Coal 3. Intercolonial Coal Co., Westville, N.S., Main seam, Drummond colliery.
Coke C1/3. Age of coal, under 21 months.
Dry coal coked, 48½ lbs. Water as coked, 7·0%. Charged Jan. 10, and coked for 48 hours.

(a) Box slightly damaged, no coke lost. Coke slightly burned, little shrinkage; a good, strong, commercial coke, sound to the top of the box, and little, if any, inferior to coke from similar fresh coal, coke C1/2003.

(b) Dense, hard coke; not very regular fracture.

(c) Class—A. Good, strong coke, slightly dull.

Coal 2003. Fresh coal, similar to coal 3.
Coke C1/2003. Age of coal, under ½ month.
Dry coal coked, 47 lbs. Water as coked, 7·0%. Coked with C1/3.

(a) Box badly damaged, but coke sound inside, although slightly burned. Little shrinkage; a good, strong, commercial coke, sound to top of box.

(b) Similar to coke C1/3, but harder and much stronger; a particularly hard coke to break.

(c) Class A. Slightly brighter than coke C1/3, but very little if any better.

Coal 49. Cumberland Ry. & Coal Co., Springhill, N.S., No. 1 Colliery.
Coke C1/49. Age of coal, under ½ month.
Dry coal coked, 46½ lbs. Water as coked, 8·8%. Charged Jan. 17, and coked for 40 hours.

(a) Sound coke to top of box; regular cleavage but breaks up readily into long, thin, curved rods; a first class coke with a very metallic ring.

(b)   Good, hard coke; very regular fracture, breaks up into small pieces but no breeze.

(c)   Class A.   Strong, compact, and good looking; prisms rather small, this is characteristic of all the Springfield cokes.

Coal 5.   Springhill No. 2 colliery.
Coke C1/5.   Age of coal, under $21\frac{1}{2}$ months.
Dry coal coked, 49 lbs.   Water as coked, $7 \cdot 6\%$.   Charged Jan. 17, and coked for 40 hours.

(a)   Badly quenched, burned in centre at top.   A good commercial coke, but shows distinct signs at the top of approaching a non-coking condition owing to age.

(b)   Medium good coke, not very strong.

(c)   Class $+$ B.   Good looking, but much fissured prismatically.

Coal 2005.   Fresh sample of coal like 5.
Coke C1/2005.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 46 lbs.   Water as coked, $9 \cdot 6\%$.   Coked with C1/5.

(a)   A good coke, sound to top and showing no lack of fusion like coke C1/5 did; regular, slightly curved cleavage.

(b)   Medium coke, fairly strong, breaks into curved rods.

(c)   Class $-$ A.   Slightly better than coke C1/5, but has the same characteristics.

Coal 6.   Springhill No. 3 colliery.
Coke C1/6.   Age of coal, under $21\frac{1}{2}$ months.
Dry coal coked, $49\frac{1}{2}$ lbs.   Water as coked, $8 \cdot 6\%$.   Charged Jan. 17, and coked for 40 hours.

(a)   Coke a trace burned at bottom.   Coke almost exactly like C1/5; a fair coke but with signs of lack of fusion at top.

(b)   Fair coke, but not very strong.

(c)   Class $+$ B; a trace better than C1/5.

Coal 2006.   Fresh sample of coal like 6.
Coke C1/2006.   Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 47 lbs.   Water as coked, $10 \cdot 3\%$.   Coked with C1/6.

(a)   Coke a trace burned, but general appearance unspoiled; an excellent coke, sound to top, similar to C1/2005; regular, slightly curved cleavage.

(b)   Harder and better coke than C1/6; breaks up more into curved regular rods.

(c)   Class A.   Distinctly better than coke C1/6.

Coal 7.   Maritime Coal, Ry., and Power Co., Chignecto colliery, N.S.
Coke C1/7.   Age of coal, under 21 months.
Dry coal coked, $45\frac{1}{2}$ lbs.   Water as coked, $7 \cdot 6\%$.   Charged Jan. 3, and coked for 48 hours.

(a) Box had hole at end, possibly a little lost. Fair coke at bottom, not very strong, but fairly good, silvery fracture; at the top there was some uncaked coal. New coal might possibly give much better coke.

(b) Very irregular coke, in parts reasonably hard, in other parts very friable.

(c) Class + B.

Coal 9. Minudie Coal Co., River Hebert, N.S., Minudie colliery.
Coke C1/9. Age of coal, under 21 months.
Dry coal coked, 51 lbs. Water as coked, 7·5%. Charged Jan. 4, and coked for 48 hours.

(a) Box badly damaged, some coke lost, hardly enough quenched. Not commercial coke, a lot of loose matter with a slight coking tendency towards the bottom. Some visible sulphur.

(b) Soft and friable, had scarcely coked.

(c) Class − B.

Coal 43. Canada West Coal Co., Taber, Alta., Canada West Colliery.
Coke C1/43. Age of coal, under 5½ months. Charged Jan. 4, and coked for 48 hours.

(a) Box badly damaged and most of contents lost. There were some lumps of coked pitch left, but otherwise coal looked unaltered, being still quite shiny in parts.

N.B.—There was no possibility of the above coal coking, but it was hoped to get a determination of loss on coking to compare with the volatile matter as determined in the laboratory; it was, however, not thought worth repeating after the above failure.

Coal 48. Leitch collieries, Passburg, Alta. Seven Foot seam or No. 1 Byron.
Coke C1/48. Age of coal, under 5½ months. Dry coal coked, 48¼ lbs. Water as coked, 6·9%. Charged Jan. 4, and coked for 48 hours.

(a) Little or no shrinkage; good sound coke from top to bottom.

(b) Bright looking, fair coke, open cellular structure, not very strong but does not produce much breeze.

(c) Class + B.

Coal 32. Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.
Coke C1/32. Age of coal, under 8 months.
Dry coal coked, 46½ lbs. Water as coked, 7·8%. Charged Jan. 2, and coked for 48 hours.

(a) Box damaged at bottom, probably very little coke lost. Little, if any shrinkage, coke not firm to the top. The coke itself was excellent in colour, hard and porous, but there were a lot of particles

of unchanged material; possibly a higher temperature might have given a very good coke.

    (b)   Bright, good looking coke, but very friable.

    (c)   Class + B.

Coal 33.   West Canadian collieries, No. 1 seam, Bellevue colliery, Alta. Coke C1/33.   Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, 47 lbs. Water as coked, 6.7%. Charged Jan. 2, and coked for 48 hours.

    (a)   Box badly damaged, coke a little burned in one place. Little if any shrinkage; had coked hard to top, regular cleavage; a fair commercial coke, but not enough fusion.

    (b)   Good, strong, tough coke; better than C1/28.

    (c)   Class + B.

Coal 28.   West Canadian collieries, No. 1 seam, Lille colliery, Alta. Coke C1/28.   Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, $46\frac{1}{2}$ lbs. Water as coked, 9.7%. Charged Jan. 2, and coked for 48 hours.

    (a)   Coal was very wet, but, like most coals, it appeared to occupy greater volume after damping than before. Box came out in poor condition, probably little lost. Shrinks a little in coking; fair coke, hard, but in spots unfused bits of coal. There was some good open cell structure at the top.

    (b)   Friable coke with a good deal of breeze.

    (c)   Class B.

Coal 34.   International Coal & Coke Co., Coleman, Alta., No. 2 seam, Denison colliery.
Coke C1/34.   Age of coal, under 8 months.
Dry coal coked, $47\frac{1}{2}$ lbs. Water as coked, 6.4%. Charged Jan. 2, and coked for 48 hours.

    (a)   Coke burned in one small spot. Little or no shrinkage, difficult to remove from box; coke is dense but crumbles when hit hard. In the top of the box, especially, there was a lot of coal which had sintered together but had not fused to form coke. Probably would be of commercial value for copper smelting.

    (b)   Medium hard coke, breaks up rather easily but without producing much breeze. Contains "white mould" (certain cokes contained patches of soft, white, fibrous matter, which resembled mould in appearance).

    (c)   Class B.

Coal 34 SP.   No. 4 seam, Denison colliery.
Coke C1/34 SP.   Age of coal, under 8 months.
Dry coal coked, 48 lbs. Water as coked, 7.0%. Charged Jan. 3, and coked for 48 hours.

(a) Slight shrinkage; good coke with marked cleavage; some particles unchanged, probably largely slaty; contains "white mould".

(b) Fairly hard coke, but cleavage not very regular.

(c) Class + B.

Coal 31. Crowsnest Pass Coal Co., No. 3 mine. Michel colliery, B.C.
Coke C1/31. Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, 48 lbs. Water as coked, 8·6%. Charged Jan. 2, and coked for 48 hours.

(a) The coal was fine and heavy. Not much shrinkage; excellent coke up to top of box.

(b) Dense, hard coke, but breaks up easily.

(c) Class + B.

Coal 30. No. 7 mine, Michel colliery, B.C.
Coke C1/30. Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, 46 lbs. Water as coked, 8·9%. Charged Jan. 2, and coked for 48 hours.

(a) Box rather damaged. Irregular cleavage; not commercial coke, had caked almost to top, but even in best coke at the bottom the shape of some of the original pieces could be seen.

(b) Very friable coke, not properly bonded; no regular cleavage.

(c) Class − B.

Coal 29. No. 8 mine, Michel colliery, B.C.
Coke C1/29. Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, $50\frac{1}{2}$ lbs. Water as coked, 11·2%. Charged Jan. 2, and coked for 48 hours.

(a) Very hard, and as there was little or no shrinkage, hard to get out of box; cleavage not very regular; a fair coke on the whole; like the Fernie cokes, but if anything less actual fusion, some pieces showing unchanged at the top.

(b) Moderately good.

(c) Class + B.

Coal 27. Crowsnest Pass Coal Co., No. 2 mine, Coal Creek, Fernie, B.C.
Coke C1/27. Age of coal, under $8\frac{1}{2}$ months.
Dry coal coked, 47 lbs. Water as coked, 9·6%. Charged Jan. 1, and coked for 48 hours.

(a) Very little shrinkage; sound coke to centre and top; a good coke, very like C1/26.

(b) Strong under hammer.

(c) Class + B.

Coal 26. No. 5 mine, Coal Creek, B.C.

Coke C1/26. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, $48\frac{1}{2}$ lbs. Water as coked, $7 \cdot 0\%$. Charged Jan. 1, and coked for 48 hours.

(a) A little spoiled by incomplete quenching. Very little shrinkage, a sound coke to centre and top; a good, hard coke.

(b) Not notably strong, but makes very little breeze in handling. More silvery in appearance than the average coke.

(c) Class+B.

Coal 25. H. W. McNeil Co., No. 1 mine, Canmore, Alta.

Coke C1/25. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, 47 lbs. Water as coked, $7 \cdot 4\%$. Charged Jan. 1, and coked for 48 hours.

(a) Box was in good condition, probably very little spilt. The coal was very little changed; there were a few traces of sintering.

(c) Class D.

This test was made to determine yield to compare with chemical analysis. Loss on coking $= 18 \cdot 4\%$ of dry coal. Volatile matter from laboratory analysis $= 17 \cdot 2\%$ of dry coal.

Coal 23 M. Bankhead Mines, Ltd., Bankhead colliery, Alta.

Coal C1/23 M. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, $46\frac{1}{2}$ lbs. Water as coked, $6 \cdot 5\%$. Charged Dec. 31, and coked for 48 hours.

(a) The lid had sunk about 2″ but the coal had hardly changed at all in appearance.

(c) Class D.

This test was made to determine yield to compare with chemical analysis. Loss on coking $= 12 \cdot 1\%$ of dry coal. Volatile matter from laboratory analysis $12 \cdot 6\%$ of dry coal. The warping of the iron boxes with the heat makes it difficult to ensure no loss when taking out of oven, when the contents are not caked.

Coal 22 SP. Nicola Valley Coal and Coke Co., Coutlee, B.C. Rat Hole seam, No. 2 mine, Middlesboro colliery.

Coke C1/22 SP. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, 46 lbs. Water as coked, $7 \cdot 1\%$. Charged Dec. 31, and coked for 48 hours.

(a) Box was badly damaged. There was a trace of caking through the bottom 3″ or 4″; the top was quite loose.

(c) Class + C.

Coal 22 M. Coal from Mines 1 and 2, Middlesboro colliery, B.C.

Coke C1/22 M. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, 45 lbs.   Water as coked, 6·0%.   Charged Dec. 31,
and coked for 48 hours.

(a)   Had not coked at all, bottom 2″ or 3″ had loosely caked.
(Sample kept was of caked part.)

(c)   Class C.

Coal 20.   Wellington Colliery Co., Wellington seam, Extension
colliery, B.C.
Coke C1/20.   Age of coal, under 9 months.
Dry coal coked, 43½ lbs.   Water as coked, 8·7%   Charged Dec. 30,
and coked for 48 hours.

(a)   Shrinks on coking; medium good coke, breaks rather easily;
good silvery cell structure in parts but more generally dirty; probably
would do for iron blast furnace.

(c)   Class — A.

Coal 18.   Western Fuel Co., Nanaimo, B.C., Upper seam, No. 1 mine.
Coke C1/18.   Age of coal, under 9 months.
Dry coal coked, 43½ lbs.   Water as coked, 8·5%.   Charged Dec. 30,
and coked for 48 hours.

(a)   Caked towards bottom of box, but loose at the top; not
commercial coke.

(c)   Class C.

Coal 17.   Lower seam, No. 1 mine, Nanaimo, B.C.
Coke C1/17.   Age of coal, under 9 months.
Dry coal coked, 45½ lbs.   Water as coked, 9·7%.   Charged Dec. 30,
and coked for 48 hours.

(a)   No real coke, though a little had caked for 3″ at the
bottom; non-coking coal.

(c)   Class C.

Coal 21.   Wellington Colliery Co., Cumberland, B.C.   Lower seam,
No. 4 mine, Comox colliery.
Coke C1/21.   Age of coal, under 8½ months.
Dry coal coked, 44½ lbs.   Water as coked, 6·3%.   Charged Dec. 30,
and coked for 48 hours.

(a)   Shrinks on coking.   Hard and dense and not much broken
up, but not very good looking coke.   The centre and top were more
caked than coke and the whole could only be described as poor coke;
on the border line of coking; might give good coke at a higher tempera-
ture, or with fresher coal.

(c)   Class — A.

Coal 21 M.   Mixture of coal from Lower seam, Mines 4 and 7, Comox
colliery.
Coke C1/21 M.   Age of coal under 8½ months.

Dry coal coked, 46 lbs. Water as coked, 8·5%. Charged Dec. 30, and coked for 48 hours.

(a) Coke very like C1/21, only distinctly better; more had really coked and less only caked.

(b) Very irregular; some strong.

(c) Class — A. Better than C1/21.

Coal Ex. 31. White Pass & Yukon Ry. Co., Whitehorse, Yukon, Upper seam, Tantalus mine.
Coke C1/Ex. 31. Age of coal, under 7 months.
Dry coal coked, 95½ lbs. (Large boxes were used for four Yukon coals). Water as coked, 9·9%. Charged Jan. 6, and coked for 48 hours.

(a) Not a commercial coke; coked or caked throughout, but coke a dirty grey colour; heavy and crumbly, like dried mortar in appearance.

(b) Dense friable material, very little regular fracture. Contains "white mould;" this was composed of hexagonal or tetragonal needle-like crystals.

(c) Class + C.

Coal Ex. 231. Coal Ex. 31, purified by washing.
Coke C1/Ex. 231. Age of coal, under 7 months.
Dry coal coked, 85 lbs. Water as coked, 7·6%. Charged Jan. 6, and coked 48 hours.

(a) Little or no shrinkage. Coke was much better and sounder than C1/Ex. 31; less crumbly though somewhat similar in appearance; a poor commercial coke. Contained a good deal of "white mould."

(b) Harder, cleaner, and less friable than C1/Ex. 31; very dense, breaks cleanly.

(c) Class — B.

Coal Ex. 32. Middle seam, Tantalus mine.
Coke C1/Ex. 32. Age of coal, under 7 months.
Dry coal coked, 95 lbs. Water as coked, 6·9%. Charged Jan. 6, and coked for 48 hours.

(a) Very like coke C1/Ex. 31. Hardly a commercial coke; more like hard mortar than coke, very heavy and contains many dirty spots.

(b) Dirty, friable agglomerate; no regular cleavage.

(c) Class — C. The Yukon cokes tested, especially the dirtier and unwashed ones, contain so much lime that on keeping they tend to disintegrate owing to the lime slaking and expanding.

Coal Ex. 232. Coal Ex. 32, purified by washing.
Coke C1/ Ex. 232. Age of coal, under 7 months.
Dry coal coked, 85 lbs. Water as coked, 5·6%. Charged Jan. 6, and coked for 48 hours.

(a) Coke not so good as C1/Ex. 231, although better than C1/ Ex. 32; might be used as a commercial coke; contains a lot of "white mould."

(b) Great improvement on C1/Ex. 32; very dense, not much breeze, but fracture not very regular.

(c) Class — B.

Coal Ex. 33. Lower seam, Tantalus mine.
Coke C1/Ex. 33. Age of coal, under 7 months.
Dry coal coked, 54 lbs. Water as coked, 12·6% Charged Jan. 6, and coked 48 hours.

(a) All the Yukon coal samples tested were chiefly coal dust, any lumps being small, and they were all difficult to moisten. Little shrinkage, sound coke to top of box; better than any of above Yukon cokes; a very fair commercial coke, probably fit for iron blast furnace although there is very little cellular structure; clean fracture, showing very curious concentric spherical markings; little or no "white mould."

(b) Dense, hard coke; not much breeze, but breaks up rather easily in any direction.

(c) Class — A.

Coal Ex. 233. Coal Ex. 33, purified by washing.
Coke C1/Ex. 233. Age of coal, under 7 months.
Dry coal coked, $52\frac{1}{2}$ lbs. Water as coked, 9·9%. Charged Jan. 6, and coked 48 hours.

(a) Little or no shrinkage; good coke, very dense; very much the same as C1/Ex. 33, not very noticeably cleaner.

(b) Like coke C1/Ex. 33, but harder and sounder.

(c) Class — A.

COKING TESTS MADE IN BEEHIVE OVEN OF THE DOMINION COAL CO., AT BRIDGEPORT NEAR GLACE BAY, N.S., JANUARY, 1909.

All the boxes coked here were charged into the oven on Jan. 18, and were coked for 72 hours; unwashed slack coal from Lingan colliery was being coked in the oven at the time.

Preliminary Tests—Comparison of Open Oven and Box Cokes.

A box was filled with wet slack coal such as was charged into the oven, and the coke produced was compared with a typical sample of the coke made at the same time in the open oven.
Box Coke, C81.

(a) Coke very bubbly on the top; broke up and tumbled out of the box easily; a good commercial coke, but would be greatly improved by washing the coal.

(b) Very pretty coke, open texture, not very strong, but does not produce much breeze.

(c) A mere trace more compact than coke from the open oven, but otherwise the cokes are the same.

Open Oven Coke, C82.

(b) Not so pretty as C81, possibly not quite so strong, otherwise almost identical.

(c) Like C81, but a mere trace less compact.

Coking Tests of Regular Coals.

Coal 2035 SP. Dominion Coal Co., Phalen seam, Dominion No. 5, N.S.

Coke C2/2035 SP. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 45 lbs. Water as coked, $6 \cdot 5\%$.

(a) Coke broke up somewhat in turning out of box. A good commercial coke; bottom half shiny black and large cell structure, top half steel grey and denser coke with a good deal of sooty deposit.

(b) Open cellular structure, dark coloured, produces a good deal of breeze. Weaker than the coke from same coal in Otto-Hoffman oven.

Coal 2008. Main seam, Acadia colliery, N.S.

Coke C2/2008. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, $48\frac{1}{2}$ lbs. Water as coked, $7 \cdot 8\%$.

(a) Coke a little burned in one spot. Coke broke up into several pieces when taking out of box, cleavage from top to bottom. A good strong coke, sound from top to bottom, but shows signs of slate.

(b) Good strong coke, hard and bright at top, black at the bottom.

Coal 6. Cumberland Ry. & Coal Co., No. 3 colliery, Springhill, N.S.

Coke C2/6. Age of coal, under $21\frac{1}{2}$ months.

Dry coal coked, $47\frac{1}{4}$ lbs. Water as coked, $5 \cdot 2\%$.

(a) Coke very crumbly, came out of box in one cake together with a quantity of loose stuff; not a commercial coke. No sample kept.

Coal 28. West Canadian collieries, No. 1 seam, Lille colliery, Alta.

Coke C2/28. Age of coal, under 8 months.

Dry coal coked, 49 lbs. Water as coked, $10 \cdot 1\%$.

(a) Coke came whole out of box. Showed unfused lumps on all faces; broke up rather easily into small lumps.

(b) Distinctly worse than coke from the same coal coked in Otto-Hoffman or Bernard ovens.

Coal 34. International Coal & Coke Co., Coleman, Alta., No. 2 seam, Denison colliery.

Coke C2/34. Age of coal, under 8 months.

Dry coal coked, $52\frac{1}{2}$ lbs. Water as coked, $9 \cdot 6\%$.

(*a*) Coke very crumbly, especially at the bottom where there was a lot of loose dust. Not a commercial coke.

(*b*) Dirty, friable coke, not properly bonded, produces a great deal of breeze.

Coal 31. Crowsnest Pass Coal Co., No. 3 mine, Michel colliery, B.C.

Coke C2/31. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, 51 lbs. Water as coked, $10 \cdot 2\%$.

(*a*) Coke came out of box in two pieces, having simply cracked vertically across the centre. Very dense, shows pieces of original coal or slate unfused; a little crumbly at the top; slight tendency towards vertical cleavage, but breaks fairly easily across also. Like other Beehive cokes made, not thoroughly coked through, shows "black ends" at the bottom.

(*b*) Like coke from same coal in Otto-Hoffman oven in appearance but softer.

Coal 26. Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie, B.C.

Coke C2/26. Age of coal, under $8\frac{1}{2}$ months.

Dry coal coked, $56\frac{1}{2}$ lbs. Water as coked, $11 \cdot 6\%$.

(*a*) Coal was very dusty. Coke appeared cracked upon the top, but only broke in two when taken out of box. Showed unfused lumps on all outside surfaces and some inside. Breaks up rather easily.

(*b*) Not so strong as the cokes from the same coal in Otto-Hoffman and Bernard ovens, softer and blacker in appearance.

COKING TESTS IN THE BERNARD AND BAUER OVENS OF THE NOVA SCOTIA STEEL & COAL CO., AT SYDNEY MINES, N.S., JANUARY, 1909.

All the tests at Sydney Mines were made in Batteries 1 and 2 of Bernard ovens, except in the case of two boxes which were coked in Bauer ovens; the boxes, with 4 exceptions, were coked for 48 hours. Mixed washed coal from Mines 1 and 3 of the Nova Scotia Steel & Coal Co. was being coked in the ovens at the time the tests were made; this is referred to as N. S. S. & C. Co. coal.

Preliminary Tests—Comparison of Bernard and Bauer Ovens, also of Open Oven and Box Coke.

Two boxes were similarly filled with N. S. S. & C. Co. coal and two with D. I. & S. Co. coal; one of each of the pairs was coked in a Bernard oven and the other in a Bauer oven. Two samples were also taken of the open oven coke from the Bernard oven.

Difficulty was experienced in pushing the Bauer oven on account of a soft spot in the vicinity of the two boxes; this was due either to the oven having been a little cool, or, more probably, to an extra wet lorry of coal.

Coke C86 from N. S. S. & C. Co. coal coked in Bernard oven 83 Jan. 23.
Wet coal coked, 47 lbs. Yield from wet coal, 58·2%.

(*a*) A good deal of shrinkage, sound coke to top, breaks up into bigger pieces than in the open oven where it breaks up into more rod-like pieces. The bottom half was very good, if anything better than the regular open oven coke, but the upper half was more cellular; the average would be about the same as the open oven coke.

(*b*) Fairly strong coke, open cellular structure, not very bright.

(*c*) A trace brighter than the open oven cokes C97 and C98, possibly due to better quenching.

Coke C88 from N. S. S. & C. Co. coal coked in Bauer oven 18 on Jan. 25.
Wet coal coked, 45½ lbs. Yield from wet coal, 61·2%.

(*a*) Good coke and sound to top, nice bright coke. Could not see any difference between this and the corresponding Bernard coke, C86, except that the bottom and top halves of the coke were more alike in C88.

(*b*) Very much the same as C86, possibly a trace brighter.

(*c*) A mere trifle worse than C86, but a trace brighter than the open oven cokes C97 and C98.

Coke C87 from D. I. & S. Co. coal coked in Bernard oven 83, Jan. 23.
Wet coal coked, 49½ lbs. Yield from wet coal, 65·4%.

(*a*) A good deal of shrinkage, came out of box rather easily. A good coke, sound to top, regular cleavage.

(*b*) Contains a considerable amount both of silvery and of sooty coke; slightly stronger than the corresponding Bauer coke.

Coke C89 from D. I. & S. Co. coal coked in Bauer oven 18, Jan. 25
Wet coal coked, 46½ lbs. Yield from wet coal, 68·9%.

(*a*) Good coke, sound to top; rather more of the large cell structure at the top than usual, this is said to be characteristic of the Bauer oven coke. The fracture of the coke in the box was more vertical than in

the case of the Otto-Hoffman cokes, probably due to the greater width of the Bauer oven.

(b) Fairly good coke, contains a good deal of smut.

(c) Almost identical with C 87.

Coke 97 from N. S. S. & C. Co. coal, coked in open Bernard oven.
Sample was taken from coke made towards the top of a Bernard oven.

(b) Very much like coke from the same coal coked in boxes in Bernard and Bauer ovens, C86 and C88. Contains a certain amount of soot.

Coke 98 from N. S. S. & C. Co. coal, coked in open Bernard oven.
Sample was taken from coke made towards the bottom of a Bernard oven.

(b) Like C97, but contained a good deal more soot.

(c) Better than C97.

Final Coking Tests of Regular Coals.

Coal 38. Dominion Coal Co., Phalen seam, Dominion No. 1, N.S.
Coke C3/38. Age of coal, 7 months.
Dry coal coked, 55 lbs. Water in coal as coked, 10%. Charged to oven, Jan. 26.

(a) Good coke, regular cleavage, fit for anything.

(b) Good, strong coke, very marked cleavage.

(c) Not so good as the corresponding Otto-Hoffman coke, C1/38, which was classed+A.

Coal 2038. Fresh sample of coal like 38.
Coke C3/2038. Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 47 lbs. Water as coked, 6·7%. Coked with C3/38.

(a) Good coke, regular cleavage; came out of box easily. Was regarded as better than C3/38, because it contained more silvery and less black coke.

(b) Very like C3/38, but not quite so strong, contained more soot and more silvery coke.

(c) Class−A. Not completely coked.

Coal 39. Lingan seam, Dominion No. 12, N.S.
Coke C3/39. Age of coal, 7 months.
Dry coal coked, 48$\frac{1}{2}$ lbs. Water as coked, 7·9%. Charged into oven Jan. 26.

(a) Had some difficulty in removing from box. An excellent coke, if anything slightly better than two preceding cokes.

(b) Practically the same as corresponding Otto-Hoffman coke, C1/39.

(c) Not so good as C1/39.

Coal 2039. Fresh sample of coal like 39.

Coke C3/2039. Age of coal, under ½ month.

Dry coal coked, 46 lbs. The box of this coal coked with C3/39 had been destroyed in the oven; the above box was filled by E. Stansfield, but was coked after he had left Sydney Mines on Jan. 30 and forwarded unopened to Montreal by Mr. J. McClennan, coke oven superintendent.

(*a*) Coke quite good, regular fracture, some long rods of coke formed.

(*b*) Like coke from coal 39 coked in Otto-Hoffman and Bernard ovens, but slightly stronger and brighter.

(*c*) Class — A.

Coal 13. Nova Scotia Steel & Coal Co., Sydney Mines, N.S., No. 1 colliery.

Coke C3/13 (2). Age of coal, under 17½ months.

Dry coal coked, 50 lbs. Water as coked, 5·0%. Charged into oven, Jan. 26.

(*a*) Very good looking coke, but breaks up very easily.

(*b*) Good, open cellular coke, but not very strong.

(*c*) Class — A.

Coke C3/13 (1). Age of coal, under 17½ months.

Dry coal coked, 52 lbs. The box of coal 2013, coked together with the above box of coal 13, was destroyed in the oven; extra boxes of coals 13 and 2013, therefore, were filled by E. Stansfield but coked after he had left Sydney Mines, as was described under C3/2039.

(*a*) Fair coke, regular fracture, but broke across very easily; contains visible slate, and shows a number of rust spots due to the coke having been left wet for some time.

(*b*) Same as C3/13 (2).

(*c*) Class — A.

Coal 2013. This was supposed to be a sample of fresh coal like coal 13. Actually the slack coal supplied was found to have a far higher ash content than the original sample of screened coal.

Coke C3/2013. Age of coal, under ½ month.

Dry coal coked, 51 lbs. Coked with C3/13 (1).

(*a*) Fair coke, but very friable, probably due to the amount of slate, etc., present; also showed rust spots owing to having been left wet. Original fracture in box quite regular. Coke very little different from C3/13, a trace more fragile, and more slaty, but possibly brighter.

(*b*) Like coke C3/13, but breaks up smaller.

(*c*) Class — A. Slightly worse than C3/13 as more friable due to presence of slate.

Coal 12. No. 3 colliery, Sydney Mines, N.S.
Coke C3/12. Age of coal, under $17\frac{1}{2}$ months.
Dry coal coked, 52 lbs. Water as coked, 8·2%. Charged into oven,
Jan. 26.

(*a*) Box was badly squeezed in oven. Black and friable coke, not
well bonded at the top, but good coke at the bottom. Said to be better
coke than C3/2012 or than could ordinarily be made from coal from
this mine by itself.

(*b*) Like the corresponding Otto-Hoffman coke, C1/12, possibly
a trace harder.

(*c*) Not so good as C1/12, which was classed +B.

Coal 2012. Slack coal from No. 3 colliery, Sydney Mines, N.S. (See
note to coal 2013).
Coke C3/2012. Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 50 lbs. Water as coked, 7·2%. Coked with C3/12.

(*a*) Box was placed too near end of oven and was badly burned.
A black coke which easily breaks up into small pieces; too weak to use
alone in an iron blast furnace.

(*b*) Like C1/12 and C3/12, but more fragile and produces more
breeze; contains considerable visible slate.

(*c*) Class B. Very friable.

Coal 10. Canada Coals & Ry. Co., Joggins colliery, N.S.
Coke C3/10. Age of coal, under $21\frac{1}{2}$ months.
Dry coal coked, 51 lbs. Water as coked, 6·8%. Charged into oven,
Jan. 25, and coked 50 hours.

(*a*) A grey coloured coke, only just coked; a lot of loose material
at the top and the bulk very weak. A great deal of slate showing,
also some sulphur. If the coal was washed free from slate it might
produce commercial coke.

(*b*) Dirty, weak coke; no regular fracture; makes a lot of breeze.

(*c*) Class B. Scarcely up to eastern standards, but would pass
in the west.

Coal 3010. Fresh sample of coal like 10.
Coke C3/3010. Age of coal, under 1 month.
Dry coal coked, 52 lbs. Water as coked, 6·8%. Coked with C3/10.

(*a*) Some good coke, but a great deal of very black or dull grey;
less slate visible than in C3/10. A commercial coke, though not good.

(*b*) Dull black coal, harder and makes less breeze than C3/10.

(*c*) Class+B. Darker in colour than C3/10, but harder and
less friable.

Coal 11. G. H. King, Kings mine, Minto, N.B.
Coke C3/11. Age of coal, under $21\frac{1}{2}$ months.
Dry coal coked, $57\frac{1}{2}$ lbs. Water as coked, 7·3%.

(a) Box damaged in oven, only fragment of coke left in broken box, but it looked to be good coke.

(b) Hard coke, no regular fracture. Not enough coke left to make physical tests.

(c) Class — A. Dense, strong coke.

Coke 48. Leitch Collieries Ltd., No. 1 or Byron seam, Passburg, Alta. Coke C3/48. Age of coal, under $5\frac{1}{2}$ months.
Dry coal coked, 56 lbs. Water as coked, 6·5%. Charged into oven, Jan. 27.

(a) The box was apparently coked wrong side up. A fair commercial coke; the outside layer, 3″ or 4″ thick, was very bright, the inside distinctly dull.

(b) Like corresponding Otto-Hoffman coke, but slightly more fragile.

Coal 32. Hillcrest Coal & Coke Co., Hillcrest, Alta.
Coke C3/32. Age of coal, under 8 months.
Dry coal coked, $55\frac{1}{2}$ lbs. Water as coked, 6·9%. Charged into oven, Jan. 26.

(a) A passable commercial coke, but very slaty and no regular cleavage; it looked as though it would come out of the box in one piece, actually it was very difficult to get out and broke up into small pieces.

(b) Like corresponding Otto-Hoffman coke.

Coal 33. West Canadian Collieries Co., No. 1 seam, Bellevue colliery, Alta.
Coke C3/33. Age of coal, under 8 months.
Dry coal coked, 49 lbs. Water as coked, 6·6%. Charged into oven, Jan. 26.

(a) A solid lump of coke, except for one crack across the middle ; no regular cleavage, very hard to get out of box. A fair coke cementing together slate and unfused particles of coal, more bonded at the bottom than at the top.

(b) Not so good as the corresponding Otto-Hoffman coke, similar but not so strong.

Coal 28. West Canadian Collieries Co., No. 1 seam, Lille colliery, Alta.
Coke C3/28. Age of coal, under 8 months.
Dry coal coked, 58 lbs. Water as coked, 8·5%. Charged into oven Jan. 27.

(a) The box was squeezed in oven; coke quite sound and only one crack across, no regular cleavage; very difficult to get from box. Coke very fair, but not well bonded.

(b) Similar to corresponding Otto-Hoffman coke.

Coal 30. Crowsnest Pass Coal Co., No. 7 mine, Michel colliery, B.C.
Coke C3/30. Age of coal, under 8½ months.
Dry coal coked, 54 lbs. Water as coked, 5·9%. Charged into oven,
Jan. 27.

(*a*) Not a commercial coke; a very little had caked, but most of
it was a loose powder. No sample kept.

Coal 29. No. 8 mine, Michel colliery, B.C.
Coke C3/29. Age of coal, under 8½ months.
Dry coal coked, 54½ lbs. Water as coked, 8·2%. Charged into oven,
Jan. 26.

(*a*) Cleavage of coke showed that the box had not been lying
square across the oven. Coke split into big pieces, some loose coke
at the top of the box; not very good anywhere, but a possible com-
mercial coke.

Coal 26. Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie,
B.C.
Coke C3/26. Age of coal, under 8½ months.
Dry coal coked, 54½ lbs. Water as coked, 10·3%. Charged into oven,
Jan. 25, and coked for 50 hours.

(*a*) A trace of loose on the top, otherwise good, strong coke from
bottom to top. Heavy coke, very little cell space, some visible slate.

(*b*) Breaks up rather easily, but makes very little breeze. In
general, like corresponding Otto-Hoffman coke.

Coal 18. Western Fuel Co., Upper seam, No. 1 mine, Nanaimo, B.C.
Coke C3/18. Age of coal, under 9 months.
Dry coal coked, 52 lbs. Water as coked, 8·0%. Charged into oven,
Jan. 27.

(*a*) Not a commercial coke; had caked at sides and bottom, but
mostly a loose dry powder with a limy smell.

Coal 21 M. Wellington Colliery Co., Cumberland, B.C., Lower seam,
Mines 4 and 7, Comox colliery.
Coke C3/21 M. Age of coal, under 8½ months.
Dry coal coked, 53 lbs. Water as coked, 7·6%. Charged into oven,
Jan. 26.

(*a*) Very solid in box. A poor commercial coke, fairly regular
cleavage, hard and dense, but very dirty.

(*b*) Much the same as the corresponding Otto-Hoffman coke, but
a trace less compact in the hardest parts.

Coal Ex. 232. White Pass & Yukon Ry. Co., Middle seam, Tantalus
mine, Yukon Territory. Coal had been washed.
Coke C3/Ex. 232. Age of coal, under 7½ months.
Dry coal coked, 50½ lbs. Water as coked, 16·4%. Charged to oven,
Jan. 23.

(*a*) Dry, crumbly, mortar-like material, of no commercial value.

COKING TESTS IN THE BERNARD OVENS OF THE WEST CANADIAN COLLIERIES CO., AT LILLE, ALTA., JULY AND AUGUST, 1909.

16 boxes of coal were coked at Lille, eight in one oven and eight in another; they were charged into the oven on August 3 and were coked for 48 hours; washed slack coal from the Lille colliery was being coked in the ovens at the time.

Preliminary Test—Comparison of Open Oven and Box Coke.

Box Coke C120. A box of wet washed slack coal from the Lille colliery, such as was being charged into the oven at the time, was coked as usual. Weight of wet coal, 47 lbs. Yield of dry coke from wet coal, 70·4%.

(*b*) Regular cleavage, small shrinkage, good appearance, compact coke, does not produce much breeze on breaking.

(*c*) Class A.

Open Oven Coke C121. A sample of coke was taken from the product of the two ovens in which the boxes were coked.

(*b*) Coke appears to contain slightly less slate than the box coke, otherwise much the same; not very good colour.

(*c*) Class A.

Final Coking Tests of Regular Coals.

Coal 2048. Leitch Collieries, Ltd., No. 1 or Byron seam, Passburg, Alta.
Coke C4/2048. Age of coal, under ½ month.
Dry coal coked, 51½ lbs. Water as coked, 8·3%.

(*a* and *b*) Not much shrinkage; no regular fracture, produces breeze when broken, a little visible slate.

(*c*) Class +B.

Coal 2032. Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.
Coke C4/2032. Age of coal, under ½ month.
Dry coal coked, 50½ lbs. Water as coked, 10%.

(*a* and *b*) Not much shrinkage and very little fracture; irregular fracture producing breeze when broken. Fairly hard coke, contains visible slate.

(*c*) Class −A.

Coal 2033. West Canadian Collieries Co., No. 1 seam, Bellevue colliery, Alta.
Coke C4/2033. Age of coal, under ½ month.
Dry coal coked, 51 lbs. Water as coked, 9·2%.

(*a* and *b*) Not much shrinkage, no regular fracture; makes breeze when broken, fairly compact and strong coke.

(*c*) Class +B.

Coal 2028. West Canadian Collieries Co., No. 1 seam, Lille colliery, Alta.

Coke C4/2028. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 49 lbs. Water as coked, 10·5%.

(*a* and *b*) Fair shrinkage and fair fracture, but friable coke and, therefore, it produces breeze; contains visible slate.

(*c*) Class +B.

Coal 2034. International Coal and Coke Co., No. 2 seam, Denison colliery, Coleman, Alta.

Coke C4/2034. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 56 lbs. Water as coked, 9·7%.

(*a* and *b*) Not much shrinkage, fracture irregular, very hard to remove from box; makes a lot of breeze and contains a good deal of visible slate.

(*c*) Class −B.

Coal 2034 SP. No. 4 seam, Denison colliery, Coleman, Alta.

Coke C4/2034 SP. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 50$\frac{1}{2}$ lbs. Water as coked, 9·2%.

(*a* and *b*) Slight shrinkage, no regular fracture, hard to get from box, a lot of visible slate.

(*c*) Class B.

Coal 2031. Crowsnest Pass Coal Co., No. 3 mine, Michel colliery, B.C.

Coke C4/2031. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 50 lbs. Water as coked, 8·8%.

(*a* and *b*) Not much shrinkage, fairly regular fracture, not much breeze, good, sound coke to top.

(*c*) Class A.

Coal 2029. No. 8 mine, Michel colliery, B.C.

Coke C4/2029. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 51 lbs. Water as coked, 12·3%.

(*a* and *b*) Dense, hard coke, sound to top of box, fair shrinkage, good fracture, hard to break, does not produce much breeze.

(*c*) Class A.

Coal 51. Hosmer Mines, Ltd., No. 2 seam south, Hosmer, B.C.

Coke C4/51. Age of coal, under $\frac{1}{2}$ month.

Dry coal coked, 51 lbs. Water as coked, 8·0%.

(*a* and *b*) Very weak coke, no regular fracture, produces a lot of breeze, contains a good deal of slaty material or unfused coal.

(*c*) Class +C.

Coal 52. No. 6 seam south, Hosmer, B.C.
Coke C4/52. Age of coal, under ½ month.
Dry coal coked, 48½ lbs. Water as coked, $7\cdot2\%$.

(*a* and *b*) Good commercial coke, not much breeze produced on breaking, regular cleavage; slight shrinkage, good colour except in centre.

(*c*) Class A.

Coal 53. No. 8 seam south, Hosmer, B.C.
Coke C4/53. Age of coal, under ½ month.
Dry coal coked, 46 lbs. Water as coked, $12\cdot8\%$.

(*a* and *b*) A very nice looking coke, very regular fracture, breaks rather easily along fracture lines to form small pieces, but produces very little breeze. Showed rather peculiar markings in the form of concentric spherical rings.

(*c*) Class A.

Coal 2027. Crowsnest Pass Coal Co., No. 2 mine, Coal Creek, Fernie, B.C.
Coke C4/2027. Age of coal, under ½ month.
Dry coal coked, 50 lbs. Water as coked, $10\cdot3\%$.

(*a* and *b*) Good looking but friable coke, slight shrinkage, a good deal of breeze formed.

(*c*) Class B.

Coal 2026. No. 5 mine, Coal Creek, Fernie, B.C.
Coke C4/2026. Age of coal, under ½ month.
Dry coal coked, 50 lbs. Water as coked, $8\cdot8\%$.

(*a* and *b*) Dense, good looking coke, fair shrinkage, regular fracture sound to top, does not produce much breeze; shows slight spherical markings, also some visible slate.

(*c*) Class—A.

Coal 2020. Wellington Colliery Co., Wellington seam, Extension colliery, B.C.
Coke C4/2020. Age of coal, under 4 months.
Dry coal coked, 43 lbs. Water as coked, $9\cdot8\%$.

(*a* and *b*) Fair coke, breaks up fairly easily, but does not produce much breeze.

(*c*) Class—A.

Coal 2018. Western Fuel Co., Upper seam, No. 1 mine, Nanaimo, B.C.
Coke C4/2018. Age of coal, under 4 months.
Dry coal coked, 44 lbs. Water as coked, $8\cdot5\%$.

(*a* and *b*) Considerable shrinkage, fair cleavage, very friable, especially at the top; has a limy smell and shows "white mould."

(*c*) Class B.

COKING TESTS MADE IN THE BEEHIVE OVENS OF THE INTERNATIONAL
COAL AND COKE CO., AT COLEMAN, ALTA., AUGUST 1909.

Three boxes were charged into one oven, and three boxes and one sack into another on the morning of August 7. The coking of the charge in the ovens appeared to be completed during the night of August 9–10 and the ovens were then closed. They were quenched and drawn on August 10, 74 hours after they were charged. Slack coal from the Denison colliery, mixed in the proportion of 2 parts from No. 4 seam to 1 part from No. 2 seam, was being coked in the ovens at this time; this coal was dry, so the boxes of coal coked here were also dry. The boxes were coked on end; the regular fracture lines in consequence sloped inwards from the perforated lid and downwards.

Preliminary Tests—Comparison of Open Oven and Box Cokes.

Box Coke C122. Coal was taken from the top of cars coming out of the mine, as nearly as was possible without weighing, in the proportion of 2 parts from No. 4 seam to 1 part from No. 2 seam. The coal was well mixed together; any big lumps found were broken up, and a box filled with the raw coal and coked.

(*a* and *b*) Dense soft coke, does not appear completely coked; slight regular fracture, but breaks in all directions; some visible slate.

(*c*) Class+B.

Open Oven Coke C123. A sample of coke was taken from the oven in which the above box was coked. Physical tests as usual were made on this sample, but no notes were made as to its appearance.

Preliminary Tests—Coking Coal in a Sack.

Samples of coal are tested by coke manufacturers most frequently by coking them in a wooden box or barrel in a regular oven; a sack has been recommended as being preferable to a box on account of the ease with which the gases can pass out, and because the coal inside is subjected to exactly the same pressure as the surrounding coal. A sack of coal was coked in a Beehive oven at Coleman; it was found that it was quite easy to separate at least the bulk of the coke produced from the surrounding coke, so that in this case the method was satisfactory. Very poor coke probably could not have been recovered, and neither the sack nor the wooden box method allows the yield of coke to be determined.

Final Coking Tests of Regular Coals.

Coal 2032. Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.
Coke C5/2032. Age of coal, under $\frac{1}{2}$ month.
Dry coal coked, 53 lbs.

(*a* and *b*) Slight shrinkage, fracture fair, but coke very easily broken; colour bright at top but dull at bottom, rather large amount of visible slate.

(*c*) Class +B.

Coal 2034 SP. No. 4 seam, Denison colliery, Coleman, Alta.
Coke C5/2034 SP. Age of coal, under ½ month.
Dry coal coked, 55 lbs.

(*a* and *b*) Not much shrinkage, no regular fracture; a good deal of visible slate, fair colour at the top.

(*c*) Class +B.

Coal 52. Hosmer Mines, Ltd., No. 6 seam south, Hosmer, B.C.
Coke C5/52. Age of coal, under ½ month.
Dry coal coked, 53 lbs.

(*a* and *b*) Fairly even fracture, considerably cracked across the seams, not much breeze produced, good colour, very little visible slate.

(*c*) Class A.

Coal 2026. Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie, B.C.
Coke C5/2026. Age of coal, under ½ month.

(*a* and *b*) Good coke, very nice appearance, fair shrinkage, regular fracture, considerably broken up along fracture lines and came easily out of box; breaks rather easily into small pieces, but does not produce much breeze.

(*c*) Class A.

Coal 2020. Wellington Colliery Co., Wellington seam, Extension colliery, B.C.
Coke C5/2020. Age of coal, under 4 months.
Dry coal coked, 48 lbs.

(*a* and *b*) Fair shrinkage, regular fracture, broke up easily into prisms of very bright, good looking coke.

(*c*) Class A.

TEMPERATURES OF COKE IN AN OTTO-HOFFMAN OVEN.

An attempt was made to record the temperatures at different points inside the charge in an Otto-Hoffman coke oven throughout the entire period of coking; the difficulties of the task undertaken, however, were not sufficiently foreseen and guarded against, and the results obtained are too unreliable to be worth publishing. The methods employed and the difficulties encountered are described below.

Six holes were drilled through the door at the quenching platform end of the oven chosen for the tests; three of these were spaced about 18″ apart down the centre line of the door, the other three were at the same

levels but near one side of the door. The observation hole near the top made a seventh opening in the door through which a pyrometer fire end could be introduced; three of the charging hole covers on the top of the oven were also drilled to allow the introduction of a pyrometer. The ten holes were stopped with clay when not in use.

The pyrometer fire ends employed were of nickel and iron, and were about 1″ external diameter; 4 ft. rods were used for the end temperatures, and 6 ft. rods for the temperatures on the top of the coke.

The test was begun half an hour after a fresh charge of coal had been introduced into the oven; the temperature was taken at each of the ten points in order, and this operation repeated every half hour until the coking was completed. A hole about 3 feet deep was made into the charge opposite the hole in the door by means of an iron rod, and the fire end then pushed to the bottom of the hole; through the holes in the charging doors on the top a fire end was put down 2″ or 3″ into the top of the charge.

The pyrometer fire end had in every case to pass through a hotter zone before it reached the point at which the temperature was to be determined; as it was made of metal, heat was fairly rapidly conducted along it from the hot portion to the nickel-iron junction at the end, and, therefore, the true temperature at that point was not recorded. To obviate this difficulty the fire ends were always left in for one minute only; this time was possibly all right for the lower temperatures at the beginning, but was not sufficient for the higher temperatures reached later on, since it was found that a different temperature was recorded according to whether the fire end was introduced hot or cold. As the temperature continued to rise more or less rapidly for some time if a fire end was left in for a longer period, it did not appear to be possible to select any length of time which would be sufficient to allow them to attain to the correct temperature without heat conduction along them vitiating the result.

The holes made into the charge opposite the holes in the door became enlarged by oxidation and mechanical abrasion until they were comparatively large conical holes, and in one case two holes side by side became united; the temperatures at the bottom of such holes could not be expected to be the same as in similar positions in the solid coke.

Four chemists from the laboratory of the Dominion Iron and Steel Co. took it in turns to take the pyrometer readings during the forty-eight hours for which the charge in the oven was coked.

ANALYSES OF GAS FROM BERNARD OVENS AT SYDNEY MINES.

In the Bernard ovens at Sydney Mines the gases given off from the coal as it is coked are mixed with air and burned in the flues around the ovens, the hot products of combustion are led away in large flues and used to heat a battery of boilers. Samples of the gas given off during the pro-

gress of the coking were taken off from the top of the charges in the ovens by means of a long iron pipe passed through the observation hole in the door of the oven. Samples of gas were also taken from the flues leading from the ovens to the boilers, and from the flue through which the gases pass after leaving the boilers. Five holes were drilled into the flues: No. 1 was in the flue from No. 1 battery, just where it left the battery and carried the mixed gases from all the ovens; No. 2 was in a corresponding position in the flue from No. 2 battery; No. 3 was in the gas inlet into the boiler nearest to No. 1 battery; No. 4 was in the gas inlet into the boiler nearest to battery No. 2; and No. 5 was in the exit flue from the boilers.

An iron pipe of about $\frac{3}{8}''$ bore and 20 feet long was used to withdraw gases from the top of an oven, a shorter pipe was used to take samples from the underground flues. Gas was aspirated through the pipe and connecting tubes, and through a glass sample tube of about 20 c.c. capacity, by means of a rubber hand pump or by a couple of large bottles, containing water, used as an aspirator, at least 5 litres of gas being drawn through. The gas sample tubes were shaped like a cylindrical pipette for liquids, but had a constriction in the tube on either side of the bulb; when they were filled with the desired gas they were temporarily closed by spring clips on the connecting rubber tubes, taken to the laboratory close by and at once sealed off at the constrictions by means of a gas flame. The samples were analysed, in Montreal, over mercury in the Bone and Wheeler gas analysis apparatus.

The samples taken were as follows:—

1. January 28, 1909. Gas from oven 44 at 1.10 p.m. This oven was pushed at 1.30 p.m. and at once recharged.

2. Gas from oven 44 at 2.10 p.m., not a reliable sample.

3. Gas from oven 44 at 2.35 p.m.

4. Gas from oven 43 at 3.45 p.m.; this oven had been charged at about 6.30 p.m. the previous day. Had trouble with soot blocking up the sampling tubes.

5. Gas from oven 44 at 4.10 p.m.

6. January 29, 1909. Gas from hole 1 at 10.30 a.m.

7. Gas from hole 3 at 11.00 a.m.

8. Gas from hole 5 at 11.30 a.m.

9. Gas from hole 4 at noon.

10. Gas from hole 2 at 1.20 p.m. Battery No. 2 had just been completely recharged when this sample was taken.

11. Gas from hole 4 at 1.40 p.m.

13. Gas from hole 3 at 2.20 p.m.

14. Gas from hole 5 at 3.05 p.m.

15. Gas from oven 87 at 3.30 p.m. This oven had been charged at 3.05 p.m., it had not yet been luted on the windward end when the sample was taken.

16. Gas from oven 88 at 3.50 p.m. This oven had been charged at about 3.00 p.m. the previous day. The wind was blowing a considerable quantity of gas out of the end of the oven at the time the sample was taken.

17. Gas from oven 22 at 4.10 p.m. This oven had been charged at 10.00 a.m. that day.

Table II gives the analysis of the gases from the ovens and Table III the analysis of the gases from the flues.

TABLE II

GAS FROM OVENS

Sample number	2	15	3	5	17	4	16	1
Oven	44	87	44	44	22	43	88	44
Time of sampling after charging hours	$\frac{1}{2}$	$\frac{1}{2}$	1	$2\frac{1}{2}$	$6\frac{1}{4}$	$21\frac{1}{4}$	$24\frac{3}{4}$	$47\frac{1}{2}$
Hydrogen %	7·7	36·3	29·2	27·7	42·4	30·0	29·8	0·7
Methane %	35·0	28·0	37·7	15·1	28·7	7·8	4·9	0·2
Ethylene %	7·7	6·9	3·6	2·9	13·5	0·3	0·0	0·0
Carbon monoxide %	2·5	7·6	1·7	5·5	4·7	9·1	15·0	5·9
Carbon dioxide %	3·9	4·3	3·4	7·6	4·7	6·4	4·8	10·0
Oxygen %	8·4	0·4	4·5	0·6	0·0	0·1	0·4	0·3
Nitrogen %	34·8	16·5	19·9	40·6	6·0	46·3	45·1	82·9
Inflammable gas %	52·9	78·8	72·2	51·2	89·3	47·2	49·7	6·8
Gross calorific value—B.T.U. per cub. ft	506	532	534	304	655	209	193	23
Net calorific value—B.T.U. per cub. ft	458	477	477	272	590	185	173	22

TABLE III

GAS FROM FLUES

Sample number	6	10	7	13	9	11	8	14
Hole number	1	2	3	3	4	4	5	5
Hydrogen %	10·3	22·4	3·2	0·0	7·9	14·1	0·0	0·0
Methane %	1·3	0·4	1·2	0·0	0·7	0·0	0·0	0·0
Ethylene %	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Carbon monoxide %	6·0	9·2	0·4	0·0	1·2	2·5	0·0	0·0
Carbon dioxide %	1·6	2·8	10·0	10·6	12·1	8·0	7·3	7·0
Oxygen %	7·3	0·0	0·2	2·3	0·1	2·0	10·8	11·0
Nitrogen %	73·5	66·2	85·0	87·1	78·0	73·4	81·9	82·0
Inflammable gas %	17·6	32·0	4·8	0·0	9·8	16·6	0·0	0·0
Gross calorific value—B.T.U. per cub. ft	66	106	24	0	36	54	0	0
Net calorific value—B.T.U. per cub. ft	59	94	21	0	32	46	0	0

THE STRENGTH OF COKE

In the report on coking experiments, Vol. I, Part VI, pages 223–5, there is a discussion of the relation of the strength of coke to its usefulness; and a description of a method of testing this strength and calculating the results.

The method used was, in brief, to crush the sample to just pass through a 1″ screen; to remove all fines which would pass a $\frac{1}{2}$″ screen; and to subject 500 grams of the material between 1″ and $\frac{1}{2}$″ to a pressure of 4200 pounds in a cylinder of nearly $5\frac{1}{4}$″ diameter. After leaving this pressure of 200 pounds per square inch on the sample for 2 minutes, the material was removed and sieved through $\frac{1}{2}$″, $\frac{5}{16}$″, and $\frac{3}{16}$″ screens and the resultant products weighed. The strength factor was then determined by dividing[1] the quantities remaining on each of the respective sizes of sieves, by the size of the last sieve the material passed through, and adding the results. Thus, in a case cited in which 500 grams were taken, 347 grams were still larger than $\frac{1}{2}$″, i.e. passed 1″; 67 grams passed $\frac{1}{2}$″; 31 grams passed $\frac{5}{16}$″; and 55 passed $\frac{3}{16}$″, and the summation, therefore, equalled $(347 \div 1) + (67 \div \frac{1}{2}) + (31 \div \frac{5}{16}) + (55 \div \frac{3}{16}) = 873 =$ Strength Factor.

It is obvious that the strength of any coke is greater as this figure is less, or, in other words, that the strengths vary more or less exactly as the reciprocals of the strength factor. If any one coke is then chosen as standard the relative strengths of the other cokes may be obtained by dividing their factors into that of the standard. The coke selected as standard for the tests reported in Vol. I had a factor of 674, therefore the coke given above has a relative strength of $674 \div 873 = 0\cdot772 = S$.

Since Vol. I was written some very interesting and valuable experiments have been carried out by Stadler and others in Johannesburg,[2] and more recently by Bell, Ball, and others at McGill University, Montreal. The result of these experiments is to prove that if a partially crushed hard material, such as rock, be first separated by sieving into a series of grades or sized products, and the material in each of these grades weighed, and if thereafter the graded material be subjected to further crushing and then regraded, then the power consumed in this crushing will be found to be a function of the change in grade, i.e., a function of the reduction in volume of the particles.

Stadler's original paper deals with this matter somewhat elaborately and recommends a particular series of sieve sizes and grades giving definite ratios of volumes, and, therefore, equally definite energy units for each grade, but it also points out the possibility of calculating the equivalent grade or energy unit of material sized or graded on sieves of any other dimensions. The work done more recently at McGill tends in a general way to confirm these conclusions by showing that the power actually con-

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[1] By an error in printing in Vol. I, p. 224, the x sign was used in place of the ÷ sign. The results are however, correctly calculated.

[2] Stadler, Grading Analyses and their Applications. Bulletin, Institution of Mining and Metallurgy, London, May 19, 1910.

sumed in crushing several different kinds of rock to different degrees is proportional within reasonable limits to the change in grading.[1]

The actual consumption of power in crushing a given quantity of any rock depends, of course, not only on the reduction in grade but also on the strength or resistance to crushing of the rock concerned, and, therefore, if we wish to compare different rocks, the results of tests made on any particular kind of rock have to be corrected or reduced to a standard by multiplying by a coefficient experimentally determined for that rock. These coefficients have only been determined for a very few rocks and further work will, no doubt, prove that they vary considerably with rocks of the same kind from different localities. It is exceedingly likely also that the coefficient for each rock will be found to change as the crushing gets down to very fine sizes in which the crystalline structure influences the strength. A great deal of work will have to be done before the theory of rock crushing can be said to be completely proved and definitely reduced to a matter of practical calculation, but even the experiments already completed suffice to show that Stadler's method affords us a more accurate means than we have heretofore had of determining, either the strength of broken rock to resist further reduction in size, or, conversely, to determine by calculation the amount of power which has been exerted in crushing rock from some previous size to its present grade.

In reviewing the section of the main report dealing with the strength of coke,[2] it occurred to the writer that it would be well to re-determine the strengths by the Stadler method and to compare the results with the relative strengths S and S^2 determined by the empirical method originally employed. Nine samples of coke were withdrawn from the Museum collection and crushed by the method already described, and average portions of the crushed fragments of each sized on the set of sieves originally used and the relative strength factors S and S^2 calculated. The equivalent energy units of these sieves were then determined and the relative strength of the material was calculated by the Stadler method. As it was difficult to arrive theoretically at a satisfactory energy unit for the material under $\frac{1}{16}$", all of which was lumped in one grade in the original tests, this material was screened in each of the 8 recent tests on a series of seven standard sieves, from 10 mesh down to 200 mesh, and the energy units determined for each grade. The results of these tests[3] are set forth in Table IV, which requires no further elucidation.

These tests show that the relative strength factor S, as originally determined, is not satisfactory, in that it does not sufficiently differentiate between a strong coke and a weak one. On the other hand, the square of this factor, or S^2 is very fairly in accordance with the result of the more recent and more scientific method of testing, and closely in

[1] Ball, Bulletin, Institution of Mining and Metallurgy, London, October, 1911.

[2] Porter, See Vol. I, p. 223.

[3] These tests and the necessary calculations were made under the author's direction by Mr. E. E. Billington, B.Sc.

parallel with it in the cases of cokes of good commercial quality. The two methods are less in accordance in the cases of weak cokes, and it has, therefore, been thought desirable to tabulate the whole series of results of the original crushing trials, and to give not only the relative strengths, S and S^2, as already reported in the summary, but also the Stadler factors as calculated for the series.

The results of the original tests and of these re-calculations are given in extenso in Table VI, which needs no explanation except in regard to the determination of the Stadler factor for the material passing through the $\frac{3}{16}''$ screen. As this material had all been discarded after the original tests, and as fresh samples of many of the cokes could not be had, it was necessary to assume a factor, and for this purpose the energy units were calculated for the fine portions of each of the eight coals tested, as per the central section of Table IV. The results are set forth in Table V, from which it will be seen that the Stadler factors for all these cokes range within the narrow limits between $11 \cdot 0$ and $13 \cdot 1$, and average almost exactly 12. This factor of 12 was, therefore, adopted and used in calculating the energy units given in column 13 of Table VI.

The above section applies only to the actual strength of the coke. In the tests reported in Vol. I it was found better to consider both the strength and the porosity of a coke when attempting to judge its commercial value from a physical standpoint. The values obtained by multiplying the square of the relative strength of each coke (S^2) by its percentage cell space or porosity (P) appeared to give the best commercial classification of the cokes.

TABLE IV

Tests of the strength of coke, being a comparison of Stansfield's and Stadler's factors as determined on eight selected samples, at McGill University, January-February, 1912

Coke Number			C₃26			C₃39			C₁21			C₃2038			C₅2034 SP.			C₂2008			C₃2013			C₃34		
Sieve opening	Stansfield factor on 500 gms.	Stadler factor on 100 gms.	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value
½"	1	0·83	82·8	414	0·69	75·4	377	0·62	77·4	387	0·64	72·4	362	0·60	68·6	343	0·57	63·2	316	0·52	47·4	237	0·39	20·6	103	0·17
¼"	2/4	3·68	11·8	118	0·43	16·0	160	0·59	12·4	124	0·46	16·4	164	0·60	13·6	136	0·50	22·8	180	0·66	22·8	228	0·84	21·8	218	0·80
3/16"	1/10	5·75	2·2	35	0·13	4·2	67	0·24	4·4	70	0·25	4·4	70	0·25	7·4	118	0·43	8·4	134	0·48	10·8	173	0·62	18·2	291	1·05
10	1/12	8·2	2·2		0·18	2·6		0·21	4·2		0·34	3·9		0·32	7·1		0·58	6·7		0·55	10·9		0·89	24·7		2·03
20	1/3·6	13·75	0·3		0·04	0·4		0·05	0·6		0·08	1·0		0·14	1·2		0·16	1·0		0·14	2·3		0·32	5·3		0·73
30	1/6	17·0	0·1		0·02	0·2		0·03	0·3		0·05	0·5		0·07	0·5		0·08	0·5		0·08	1·2		0·20	2·3		0·39
50	1/6	19·0	0·2	96	0·04	0·2	112	0·04	0·3	165	0·06	0·6	197	0·11	0·5	277	0·09	0·7	293	0·13	1·4	507	0·27	2·4	1072	0·46
70	1/6	20·5	0·1		0·02	0·1		0·02	0·2		0·04	0·4		0·08	0·3		0·06	0·5		0·10	0·9		0·18	1·5		0·31
120	1/6	22·5	0·2		0·04	0·2		0·04	0·2		0·04	0·4		0·09	0·3		0·07	0·6		0·13	0·9		0·20	1·4		0·31
200	1/6	25·0	0·1		0·02	0·3		0·07	0·2		0·05	0·3		0·07	0·2		0·05	0·4		0·10	0·6		0·15	0·9		0·22
−200	1/6	28·0	0·2		0·05	0·2		0·05	0·2		0·05	0·3		0·08	0·2		0·08	0·5		0·05	0·8		0·22	1·4		0·39
Stadler's energy units— Total					1·66			1·96			2·06			2·41			2·64			3·03			4·28			6·86
Relative strength standard=1·69					1·02			0·86			0·82			0·70			0·64			0·56			0·40			0·25
Factor of strength				663			716			746			793			874			923			1145			1684	
Relative strength S standard=674				1·02			0·94			0·90			0·85			0·77			0·73			0·59			0·40	
Square of relative strength—S²				1·04			0·88			0·81			0·72			0·59			0·53			0·35			0·16	

NOTE:—Standard coke referred to is explained in Vol. I, on page 225. Its Stadler total is taken as 1·69 and its relative strength as 674.

If these results be compared with the original tests made approximately three years ago, it will be found that while the samples show relatively the same order of strength, yet the weaker cokes have fallen off considerably as compared with the stronger; this is no doubt due to the weathering of the cokes themselves, which have been exposed in open trays. Minor discrepancies such as shown by C₃26 in which the strength has apparently increased, are due to the fact that the second lot of samples had been selected for exhibition and were probably somewhat stronger than the average.

TABLE V

Calculation of the Stadler factor for coke passing through a $\frac{3}{16}''$ screen

Coke Number	$C_3 26$	$C_3 39$	$C_1 21$	$C_3 2038$	$C_5 2034SP.$	$C_2 2008$	$C_3 2013$	$C_2 34$
Per cent through $\frac{3}{16}''$ screen	3·4	4·2	6·2	7·3	10·4	10·9	19·0	39·9
Sum of Stadler values	0·41	0·51	0·71	0·96	1·14	1·37	2·43	4·84
Stadler Sum ÷ Per cent of material × 100	12·0	12·1	11·5	13·1	11·0	12·5	12·8	12·1

TABLE VI

Detailed results of coke crushing tests arranged geographically by coal fields; with the relative strengths tabulated, as reported by Mr. Stansfield in the summary tables, Vol. I, Part VI, and also the Stadler values and energy units as recently determined.

Coke Number	Weight on $\frac{1}{2}''$ = grams	Weight on $\frac{5}{16}''$ = grams	Weight on $\frac{3}{16}''$ = grams	Weight through $\frac{3}{16}''$ = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material. On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$	Stadler's energy units, total	Mean total	Relative strength values. S^2	Stadler, standard =1.69
								SYDNEY COAL-FIELD.								
C 1/50.....	302	93	39	65	1	965	926	0·729	0·50	0·68	0·45	1·56	3·19	3·00	0·53	0·56
	361	44	33	63	−1	886			0·60	0·32	0·38	1·51	2·81			
C 1/36.....	382	61	25	32	0	754	754	0·894	0·63	0·45	0·29	0·77	2·14	2·14	0·80	0·79
C 1/2036...	383	46	25	46	0	799	774	0·870	0·64	0·34	0·29	1·10	2·37	2·22	0·76	0·76
	393	50	22	32	3	749			0·65	0·37	0·25	0·77	2·04			
C 1/35.....	385	42	26	48	−1	803	823	0·819	0·64	0·31	0·30	1·15	2·40	2·49	0·67	0·68
	371	48	26	54	1	843			0·62	0·35	0·30	1·30	2·57			
C 1/2035...	353	62	31	53	1	862	862	0·780	0·59	0·46	0·36	1·27	2·68	2·68	0·61	0·63
C 1/35 SP...	417	34	18	30	1	709	709	0·951	0·69	0·25	0·21	0·72	1·87	1·87	0·90	0·90
C 1/2035SP.	393	48	21	38	0	759	753	0·895	0·65	0·35	0·24	0·91	2·15	2·10	0·80	0·81
	409	31	20	38	2	748			0·68	0·23	0·23	0·91	2·05			
C 2/2035SP.	301	68	43	93	−5	1044	1088	0·619	0·50	0·50	0·49	2·23	3·72	3·93	0·38	0·43
	275	70	50	107	−2	1132			0·46	0·52	0·58	2·57	4·13			
C 1/38.....	385	67	22	29	−3	729	711	0·948	0·64	0·49	0·25	0·70	2·08	1·92	0·90	0·88
	420	36	16	25	3	693			0·70	0·27	0·18	0·60	1·75			
C 1/38.....	409	37	22	32	0	725	726	0·930	0·68	0·27	0·25	0·77	1·97	1·98	0·86	0·85
	399	50	21	30	0	727			0·66	0·37	0·24	0·72	1·99			
C 3/38.....	392	52	22	34	0	746	724	0·931	0·65	0·38	0·25	0·82	2·10	1·99	0·87	0·85
	417	37	17	30	−1	701			0·69	0·27	0·20	0·72	1·88			
C 3/2038...	382	51	25	44	−2	787	785	0·859	0·63	0·38	0·29	1·06	2·36	2·32	0·74	0·73
	381	55	24	40	0	782			0·63	0·40	0·28	0·96	2·27			
C 1/37.....	350	61	31	57	1	880	896	0·752	0·58	0·45	0·36	1·37	2·76	2·88	0·57	0·59
	328	76	38	60	−2	911			0·55	0·56	0·44	1·44	2·99			
C 1/2037...	352	61	33	55	−1	872	853	0·789	0·58	0·45	0·38	1·32	2·73	2·64	0·62	0·64
	355	68	31	46	0	834			0·59	0·50	0·36	1·10	2·55			
C 1/39.....	399	44	23	35	−1	741	743	0·907	0·66	0·32	0·26	0·84	2·08	2·07	0·82	0·82
	398	40	24	34	0	745			0·66	0·29	0·28	0·82	2·05			
C 3/39.....	437	20	18	25	0	670	683	0·987	0·73	0·15	0·21	0·60	1·69	1·78	0·97	0·95
	415	41	18	28	−2	695			0·69	0·30	0·21	0·67	1·87			
C 3/2039...	397	42	22	37	2	758	789	0·857	0·66	0·31	0·25	0·89	2·11	2·29	0·73	0·74
	360	70	25	44	1	819			0·60	0·51	0·29	1·06	2·46			
C 3/13.....	417	25	20	42	−4	734	769	0·877	0·69	0·18	0·23	1·01	2·11	2·28	0·77	0·74
	377	53	25	47	−2	806			0·63	0·39	0·29	1·13	2·44			

TABLE VI—Continued

Coke Number	Weight on 1/2" = grams	Weight on 5/16" = grams	Weight on 3/16" = grams	Weight through 3/16" = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material. On 1/2"	On 5/16"	On 3/16"	Through 3/16"	Stadler's energy units, total	Mean total	Relative strength values. S²	Stadler, standard = 1·69
SYDNEY COAL-FIELD—Continued																
C13/13....	367 / 348	55 / 78	26 / 25	51 / 47	1 / 2	829 / 846	837	0·805	0·61 / 0·58	0·40 / 0·57	0·30 / 0·29	1·22 / 1·13	2·53 / 2·57	2·55	0·65	0·66
C 3/2013...	341 / 372	59 / 43	30 / 29	69 / 56	1 / 0	928 / 850	889	0·760	0·57 / 0·62	0·43 / 0·32	0·35 / 0·33	1·66 / 1·34	3·01 / 2·61	2·81	0·58	0·60
C 1/12....	312 / 367	91 / 62	39 / 26	57 / 46	1 / −1	926 / 813	870	0·774	0·52 / 0·61	0·67 / 0·46	0·45 / 0·30	1·37 / 1·10	3·01 / 2·47	2·74	0·60	0·62
C 3/12....	392	37	23	48	0	796	796	0·848	0·65	0·27	0·26	1·15	2·33	2·33	0·72	0·73
C 3/2012...	245 / 249	102 / 78	59 / 71	94 / 100	0 / 2	1136 / 1173	1155	0·584	0·41 / 0·41	0·75 / 0·57	0·68 / 0·82	2·25 / 2·40	4·09 / 4·20	4·15	0·34	0·41
INVERNESS COAL-FIELD.																
C 1/15....	284	66	58	92	0	1090	1090	0·618	0·47	0·49	0·67	2·21	3·84	3·84	0·38	0·44
PICTOU COAL-FIELD.																
C 1/2004...	251	80	63	106	0	1175	1175	0·575	0·42	0·59	0·72	2·54	4·27	4·27	0·33	0·40
C 1/16....	428 / 425	26 / 37	18 / 15	25 / 20	3 / 3	688 / 671	679	0·995	0·71 / 0·71	0·19 / 0·27	0·21 / 0·17	0·60 / 0·48	1·71 / 1·63	1·67	0·99	1·01
C 1/2016...	431 / 400	27 / 47	18 / 29	24 / 26	0 / −2	673 / 717	695	0·970	0·72 / 0·66	0·20 / 0·35	0·21 / 0·33	0·58 / 0·62	1·71 / 1·96	1·84	0·94	0·92
C 1/1....	301	73	46	81	−1	1020	1020	0·661	0·50	0·54	0·53	1·94	3·51	3·51	0·44	0·48
C 1/2002...	408 / 447	47 / 19	17 / 12	28 / 20	0 / 2	706 / 640	673	1·000	0·68 / 0·74	0·35 / 0·14	0·20 / 0·14	0·67 / 0·48	1·90 / 1·50	1·70	1·00	0·99
C 1/8....	442 / 433	27 / 34	12 / 16	17 / 16	2 / 1	635 / 643	639	1·054	0·73 / 0·72	0·20 / 0·25	0·14 / 0·18	0·41 / 0·38	1·48 / 1·53	1·51	1·11	1·12
C 1/2008...	450 / 400	21 / 51	12 / 22	17 / 27	0 / 0	620 / 717	669	1·008	0·75 / 0·66	0·15 / 0·38	0·14 / 0·25	0·41 / 0·65	1·45 / 1·94	1·70	1·02	0·99
C 2/2008...	387	40	27	44	2	799	799	0·845	0·64	0·29	0·31	1·06	2·30	2·30	0·71	0·74
C 1/3....	375 / 420	69 / 23	23 / 22	32 / 33	1 / 2	764 / 724	744	0·906	0·62 / 0·70	0·51 / 0·17	0·26 / 0·25	0·77 / 0·79	2·16 / 1·91	2·04	0·82	0·83
C 1/2003...	408 / 437	41 / 19	21 / 14	28 / 24	2 / 6	718 / 681	700	0·961	0·68 / 0·73	0·30 / 0·14	0·24 / 0·16	0·67 / 0·58	1·89 / 1·61	1·75	0·92	0·97

TABLE VI—Continued.

Coke Number	Weight on 1/2" = grams	Weight on 5/16" = grams	Weight on 3/16" = grams	Weight through 3/16" = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material.				Stadler's energy units, total	Mean total	Relative strength values.	
									On 1/2"	On 5/16"	On 3/16"	Through 3/16"			S²	Stadler, standard = 1.69
SPRINGHILL COAL-FIELD.																
C 1/49.....	417	43	21	21	−2	671	671	1.005	0.69	0.32	0.24	0.50	1.75	1.69	1.01	1.00
	433	24	19	21	3	671			0.72	0.18	0.22	0.50	1.62			
C 1/5......	383	66	25	34	−8	735	754	0.895	0.64	0.49	0.29	0.82	2.24	2.24	0.80	0.75
	381	58	23	38	0	774			0.63	0.43	0.26	0.91	2.23			
C 1/2005...	411	41	20	26	2	707	728	0.926	0.68	0.30	0.23	0.62	1.83	1.94	0.86	0.87
	383	65	20	29	3	749			0.64	0.48	0.23	0.70	2.05			
C 1/6......	380	47	31	43	−1	798	785	0.857	0.63	0.35	0.36	1.03	2.37	2.32	0.73	0.73
	394	41	24	43	−2	772			0.65	0.30	0.28	1.03	2.26			
C 1/2006...	410	43	21	26	0	703	694	0.971	0.68	0.32	0.24	0.62	1.86	1.83	0.94	0.92
	425	31	18	27	−1	685			0.71	0.23	0.21	0.65	1.80			
JOGGINS-CHIGNECTO COAL-FIELD.																
C 1/7......	350	55	33	56	6	896	896	0.753	0.58	0.40	0.38	1.34	2.70	2.70	0.57	0.63
C 1/9......	285	79	45	91	0	1069	1069	0.629	0.47	0.58	0.52	2.18	3.75	3.75	0.40	0.45
C 3/10.....	334	51	36	74	5	972	972	0.691	0.55	0.38	0.41	1.77	3.11	3.11	0.48	0.54
C 3/3010...	385	57	24	34	0	758	758	0.889	0.64	0.42	0.28	0.82	2.16	2.16	0.79	0.78
FRANK COAL-FIELD.																
C 1/48.....	287	80	50	83	0	1047	1013	0.668	0.48	0.59	0.58	1.99	3.64	3.47	0.45	0.49
	305	82	44	70	−1	978			0.51	0.60	0.51	1.68	3.30			
C 3/48.....	293	91	44	69	3	1000	1005	0.670	0.49	0.67	0.51	1.65	3.32	3.41	0.45	0.50
	315	57	47	84	−3	1010			0.52	0.42	0.54	2.02	3.50			
C 4/2048...	260	94	50	97	−1	1120	1102	0.612	0.43	0.69	0.58	2.33	4.03	3.93	0.37	0.43
	287	72	46	95	0	1085			0.48	0.53	0.53	2.28	3.82			
C 1/32.....	321	72	36	70	1	956	958	0.705	0.53	0.53	0.41	1.68	3.15	3.13	0.50	0.54
	307	89	38	62	4	959			0.51	0.66	0.44	1.49	3.10			
C 3/32.....	317	67	47	75	−6	969	989	0.681	0.53	0.49	0.54	1.80	3.36	3.43	0.46	0.49
	289	94	43	76	−2	1009			0.48	0.69	0.50	1.82	3.49			
C 4/2032...	304	92	36	68	0	966	949	0.710	0.50	0.68	0.41	1.63	3.22	3.16	0.50	0.54
	296	101	40	65	−2	962			0.49	0.74	0.46	1.56	3.25			
	352	43	37	70	−2	919			0.58	0.32	0.43	1.68	3.01			
C 5/2032...	336	71	37	57	−1	895	937	0.720	0.56	0.52	0.43	1.37	2.88	3.11	0.52	0.54
	304	75	49	72	0	995			0.50	0.55	0.56	1.73	3.34			
	340	55	41	70	−6	922			0.56	0.40	0.47	1.68	3.11			

TABLE VI—Continued

| Coke Number | Weight on $\frac{1}{2}''$ = grams | Weight on $\frac{5}{16}''$ = grams | Weight on $\frac{3}{16}''$ = grams | Weight through $\frac{3}{16}''$ = grams | Weight lost grams | Factor | Mean factor | Relative strength S | Stadler's values for material. | | | | Stadler's energy units, total | Mean total | Relative strength values. | |
									On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$			S²	Stadler, standard = 1·69
							FRANK COAL-FIELD—Continued.									
C 1/33.....	388	51	23	38	0	767	787	0·857	0·64	0·38	0·26	0·91	2·19	2·29	0·73	0·74
	381	45	28	46	0	807			0·63	0·33	0·32	1·10	2·38			
C 3/33.....	333	78	31	59	−1	897	914	0·738	0·55	0·57	0·36	1·42	2·90	2·97	0·54	0·57
	343	48	42	68	−1	930			0·57	0·35	0·48	1·63	3·03			
C 4/2033...	378	49	25	48	0	810	839	0·803	0·63	0·36	0·29	1·15	2·43	2·72	0·64	0·62
	319	74	42	66	−1	948			0·53	0·54	0·48	1·58	3·13			
	355	61	29	56	−1	862			0·59	0·45	0·33	1·34	2·71			
	368	49	29	55	−1	845			0·61	0·36	0·33	1·32	2·62			
C 1/28.....	306	64	46	82	2	1028	1031	0·653	0·51	0·47	0·53	1·97	3·48	3·50	0·43	0·48
	279	97	47	75	2	1033			0·46	0·71	0·54	1·80	3·51			
C 2/28.....	218	110	63	112	−3	1218	1216	0·554	0·36	0·81	0·72	2·69	4·58	4·55	0·31	0·37
	250	75	54	122	−1	1214			0·41	0·55	0·62	2·93	4·51			
C 3/28.....	316	73	39	70	2	971	994	0·679	0·52	0·54	0·45	1·68	3·19	3·30	0·46	0·51
	308	69	40	80	3	1016			0·51	0·51	0·46	1·92	3·40			
C 4/2028...	329	67	37	68	−1	936	951	0·709	0·55	0·49	0·43	1·68	3·10	3·16	0·50	0·53
	349	65	31	56	−1	870			0·58	0·48	0·36	1·34	2·76			
	293	95	46	66	0	980			0·49	0·70	0·53	1·58	3·30			
	296	77	49	78	0	1020			0·49	0·57	0·56	1·87	3·49			
C 1/34.....	351	56	37	59	−3	880	888	0·761	0·58	0·41	0·43	1·42	2·84	2·80	0·58	0·60
	332	78	34	52	4	896			0·55	0·57	0·39	1·25	2·76			
C 2/34.....	146	83	77	193	1	1593	1593	0·423	0·24	0·61	0·89	4·63	6·37	6·37	0·18	0·27
C 4/2034...	274	82	55	88	1	1086	1090	0·619	0·45	0·60	0·63	2·11	3·79	4·01	0·38	0·42
	286	73	49	90	2	1077			0·47	0·54	0·56	2·16	3·73			
	210	127	60	103	0	1205			0·35	0·93	0·69	2·47	4·44			
	256	100	54	88	2	1106			0·42	0·74	0·62	2·11	4·09			
C 1/34 SP..	389	39	27	43	2	792	810	0·832	0·65	0·29	0·31	1·03	2·28	2·37	0·69	0·71
	362	63	28	45	2	827			0·60	0·46	0·32	1·08	2·46			
C 4/2034 SP	266	84	53	98	−1	1118	1116	0·604	0·44	0·62	0·61	2·35	4·02	4·02	0·36	0·42
	251	102	57	91	−1	1114			0·42	0·75	0·66	2·18	4·01			
C 5/2034 SP	325	75	42	57	1	918	900	0·749	0·54	0·55	0·48	1·37	2·94	2·85	0·56	0·59
	337	70	38	54	1	892			0·56	0·51	0·44	1·29	2·80			
	346	60	37	57	0	888			0·57	0·44	0·43	1·37	2·81			
							CROWSNEST COAL-FIELD.									
C 1/31.....	447	15	15	24	−1	649	658	1·023	0·74	0·11	0·17	0·58	1·60	1·64	1·05	1·03
	429	34	14	23	0	666			0·71	0·25	0·16	0·55	1·67			
C 2/31.....	336	54	40	69	1	945	951	0·709	0·56	0·40	0·46	1·65	3·07	3·11	0·50	0·54
	322	69	40	69	0	956			0·53	0·51	0·46	1·65	3·15			

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}''$ =grams	Weight on $\frac{5}{16}''$ =grams	Weight on $\frac{3}{16}''$ =grams	Weight through $\frac{1}{16}''$ =grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$			S²	Stadler, standard =1·69

CROWSNEST COAL-FIELD—Continued.

Coke Number	Weight on $\frac{1}{2}''$ =grams	Weight on $\frac{5}{16}''$ =grams	Weight on $\frac{3}{16}''$ =grams	Weight through $\frac{1}{16}''$ =grams	Weight lost grams	Factor	Mean factor	Relative strength S	On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$	Stadler's energy units, total	Mean total	S²	Stadler, standard =1·69
C 4/2031...	364	71	26	39	0	797			0·60	0·52	0·30	0·94	2·46			
	391	43	26	41	—0	774	774	0·870	0·65	0·32	0·30	0·98	2·25	2·30	0·76	0·73
	375	72	24	32	—3	750			0·62	0·58	0·28	0·77	2·20			
C 1/30.....	357	50	35	57	1	878	878	0·768	0·59	0·37	0·40	1·37	2·73	2·73	0·59	0·62
C 1/29.....	367	67	25	42	—1	798			0·61	0·49	0·29	1·01	2·40			
	425	31	12	32	0	694	746	0·904	0·71	0·23	0·14	0·77	1·85	2·13	0·82	0·79
C 3/29.....	406	20	24	41	9	790			0·67	0·15	0·28	0·98	2·08			
	407	37	21	37	—2	736	763	0·883	0·68	0·27	0·24	0·89	2·08	2·08	0·78	0·81
C 4/2029...	406	52	18	24	0	695			0·67	0·38	0·21	0·58	1·84			
	387	49	29	35	0	764	730	0·922	0·64	0·36	0·33	0·84	2·17	2·01	0·85	0·84
C 4/51.....	195	100	74	133	—2	1326			0·32	0·74	0·85	3·19	5·10			
	187	94	74	146	—1	1381			0·31	0·69	0·85	3·50	5·35			
	169	113	71	147	0	1406	1318	0·514	0·28	0·83	0·82	3·52	5·45	5·14	0·26	0·33
	227	96	53	124	0	1246			0·38	0·71	0·61	2·97	4·67			
C 4/52.....	369	65	25	41	0	796			0·61	0·48	0·29	0·98	2·36			
	392	43	24	42	—1	772	784	0·859	0·65	0·32	0·28	1·01	2·26	2·31	0·74	0·73
C 5/52.....	423	30	17	32	—2	696			0·70	0·22	0·20	0·77	1·89			
	398	43	23	36	0	749	728	0·927	0·66	0·32	0·26	0·86	2·10	2·01	0·86	0·84
	400	44	22	34	0	738			0·66	0·32	0·25	0·82	2·05			
C 4/53.....	389	43	22	45	1	789			0·65	0·32	0·25	1·08	2·30			
	380	48	25	46	1	805	797	0·848	0·63	0·35	0·29	1·10	2·37	2·34	0·72	0·72
C 1/27.....	426	35	13	28	—2	678			0·71	0·26	0·15	0·67	1·79			
	436	27	14	28	—5	659	669	1·008	0·72	0·20	0·16	0·67	1·75	1·77	1·02	0·96
C 4/2027...	380	48	29	43	0	797			0·63	0·35	0·33	1·03	2·34			
	403	31	25	40	1	762	780	0·862	0·67	0·23	0·29	0·96	2·15	2·25	0·74	0·75
C 1/26.....	361	61	32	46	0	831			0·60	0·45	0·37	1·10	2·52			
	414	27	25	31	3	730	781	0·863	0·69	0·20	0·29	0·74	1·92	2·22	0·74	0·76
C 2/26.....	332	53	41	74	0	963			0·55	0·39	0·47	1·78	3·19			
	310	67	40	82	1	1014	989	0·681	0·51	0·49	0·46	1·97	3·43	3·31	0·46	0·51
C 3/26.....	423	26	17	32	2	711			0·70	0·19	0·20	0·77	1·86			
	397	50	22	31	0	733	722	0·934	0·66	0·37	0·25	0·74	2·02	1·94	0·87	0·87
C 4/2026...	395	51	23	32	—1	735			0·66	0·38	0·26	0·77	2·07			
	387	49	28	36	0	766	753	0·892	0·64	0·36	0·32	0·86	2·18	2·14	0·80	0·79
	400	35	27	39	—1	757			0·66	0·26	0·31	0·94	2·17			
C 5/2026...	413	34	22	31	0	715			0·69	0·25	0·25	0·74	1·93			
	399	49	22	32	—2	728	721	0·935	0·66	0·36	0·25	0·77	2·04	1·98	0·87	0·85
	410	38	20	32	0	720			0·68	0·28	0·23	0·77	1·96			

TABLE VI—Continued

Coke Number	Weight on 1/2" = grams	Weight on 5/16" = grams	Weight on 3/16" = grams	Weight through 3/16" = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On 1/2"	On 5/16"	On 3/16"	Through 3/16"			S²	Stadler, standard = 1·69
SIMILKAMEEN COAL-FIELD.																
C 1/Ex. 2..	410	31	24	35	0	735	735	0·919	0·68	0·23	0·28	0·84	2·03	2·03	0·84	0·83
C 1/Ex. 202	428	27	18	27	0	683	693	0·970	0·71	0·20	0·21	0·65	1·77	1·80	0·94	0·94
	420	31	20	28	1	702			0·70	0·23	0·23	0·67	1·83			
C 1/Ex. 3..	292	94	50	62	2	981	981	0·687	0·48	0·69	0·58	1·49	3·24	3·24	0·47	0·52
NICOLA VALLEY COAL-FIELD.																
C 1/22SP...	275	93	51	81	0	1055	1055	0·639	0·46	0·68	0·59	1·94	3·67	3·67	0·41	0·46
NANAIMO COAL-FIELD.																
C 1/20.....	367	62	27	43	1	812	819	0·822	0·61	0·46	0·31	1·03	2·41	2·44	0·68	0·69
	369	52	33	46	0	825			0·61	0·38	0·38	1·10	2·47			
C 4/2020...	370	63	23	44	0	803	781	0·863	0·61	0·46	0·26	1·06	2·39	2·28	0·74	0·74
	384	56	21	39	0	770			0·64	0·41	0·24	0·94	2·23			
	376	57	27	40	0	788			0·62	0·42	0·31	0·96	2·31			
	376	58	27	39	0	785			0·62	0·43	0·31	0·94	2·30			
	385	49	24	42	0	783			0·64	0·36	0·28	1·01	2·29			
	398	43	21	38	0	752			0·66	0·32	0·24	0·91	2·13			
C 5/2020...	384	60	25	32	−1	748	774	0·871	0·64	0·44	0·29	0·77	2·14	2·29	0·76	0·74
	389	54	20	39	−2	758			0·65	0·40	0·23	0·94	2·22			
	358	72	28	44	−2	815			0·60	0·53	0·32	1·06	2·51			
C 1/18.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
C 4/2018...	296	62	44	97	1	1080	1031	0·654	0·49	0·46	0·51	2·33	3·79	3·40	0·43	0·50
	283	86	47	84	0	1050			0·47	0·63	0·54	2·02	3·66			
	306	83	46	65	0	964			0·51	0·61	0·53	1·56	3·21			
	347	55	34	65	−1	905			0·58	0·40	0·39	1·56	2·93			
C 1/17.....	184	109	84	127	−4	1323	1323	0·508	0·31	0·80	0·97	3·05	5·13	5·13	0·26	0·33
C 1/21.....	366	64	26	45	−1	812	809	0·833	0·61	0·47	0·30	1·08	2·46	2·43	0·69	0·70
	382	44	28	47	−1	805			0·63	0·32	0·32	1·13	2·40			
C1/21M...	391	38	31	42	−2	780	793	0·849	0·65	0·28	0·36	1·01	2·30	2·39	0·72	0·71
	367	65	26	45	−3	805			0·61	0·48	0·30	1·08	2·47			
C 3/21M...	411	34	19	36	0	733	733	0·919	0·68	0·25	0·22	0·86	2·01	2·01	0·84	0·84

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}''$ = grams	Weight on $\frac{5}{16}''$ = grams	Weight on $\frac{3}{16}''$ = grams	Weight through $\frac{3}{16}''$ = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$			S²	Stadler, standard = 1.69
WHITEHORSE COAL-FIELD.																
C 1/Ex. 31.	339 365	57 51	36 24	67 58	1 2	930 864	897	0·751	0·56 0·61	0·42 0·38	0·41 0·28	1·61 1·39	3·00 2·66	2·83	0·56	0·60
C 1/Ex. 231	394 407	50 40	23 21	34 31	−1 1	745 726	736	0·918	0·65 0·68	0·37 0·29	0·26 0·24	0·82 0·74	2·10 1·95	2·03	0·84	0·83
C 1/Ex. 32.	304	76	44	73	3	1002	1002	0·672	0·50	0·56	0·51	1·75	3·32	3·32	0·45	0·51
C 1/Ex. 232	364 315	45 80	40 45	54 61	−3 −1	852 939	896	0·751	0·60 0·52	0·33 0·59	0·46 0·52	1·29 1·46	2·68 3·09	2·89	0·56	0·59
C 1/Ex. 33.	385 370	51 69	27 28	37 35	0 −2	769 773	771	0·872	0·64 0·61	0·38 0·51	0·31 0·32	0·89 0·84	2·22 2·28	2·25	0·76	0·75
C 1/Ex. 233	404 430	44 32	27 16	24 21	1 1	713 662	688	0·980	0·67 0·71	0·32 0·24	0·31 0·18	0·58 0·50	1·88 1·63	1·76	0·96	0·96
SPECIAL COKES.																
C 1........	416	33	16	34	1	721	721	0·934	0·69	0·24	0·18	0·82	1·93	1·93	0·87	0·88
C 4........	408 435	50 25	16 16	26 23	0 1	699 655	682	0·989	0·68 0·72	0·37 0·18	0·18 0·18	0·62 0·55	1·85 1·63	1·74	0·98	0·97
C 5........	429 387	26 52	17 22	29 40	−1 −1	683 768	726	0·930	0·71 0·64	0·19 0·38	0·20 0·25	0·70 0·96	1·80 2·23	2·02	0·87	0·84
C 6........	434 425	26 29	15 18	25 28	0 0	669 691	680	0·991	0·72 0·71	0·19 0·21	0·17 0·21	0·60 0·67	1·68 1·80	1·74	0·98	0·97
C 7........	404 411	40 37	18 21	27 30	11 1	745 718	732	0·920	0·67 0·68	0·29 0·27	0·21 0·24	0·65 0·72	1·82 1·91	1·87	0·85	0·90
C 8........	406 433	39 24	20 13	38 26	−3 4	736 684	710	0·949	0·67 0·72	0·29 0·18	0·23 0·15	0·91 0·62	2·10 1·67	1·89	0·90	0·89
C 9........	381 410	60 32	24 18	36 39	−1 1	764 746	755	0·893	0·63 0·68	0·44 0·24	0·28 0·21	0·86 0·94	2·21 2·07	2·14	0·80	0·79
C 10.......	399	33	21	46	1	781	781	0·861	0·66	0·24	0·24	1·10	2·24	2·24	0·74	0·75
C 11.......	367 416	71 31	26 23	39 31	−3 −1	783 710	747	0·903	0·61 0·69	0·52 0·23	0·30 0·20	0·94 0·74	2·37 1·92	2·15	0·82	0·79
C 12.......	431 398	30 58	14 17	25 32	0 −5	671 713	692	0·974	0·72 0·66	0·22 0·43	0·16 0·20	0·60 0·77	1·70 2·06	1·88	0·95	0·90
C 13.......	409 432	36 26	24 15	31 27	0 0	724 677	701	0·961	0·68 0·72	0·27 0·19	0·28 0·17	0·74 0·65	1·97 1·73	1·85	0·92	0·91

Coke Number	Weight on $\frac{1}{2}''$ = grams	Weight on $\frac{5}{16}''$ = grams	Weight on $\frac{3}{16}''$ = grams	Weight through $\frac{3}{16}''$ = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$			S_2	Stadler, standard =1·69

SPECIAL COKES—Continued

Coke Number	Weight on $\frac{1}{2}''$	Weight on $\frac{5}{16}''$	Weight on $\frac{3}{16}''$	Weight through $\frac{3}{16}''$	Weight lost	Factor	Mean factor	Relative strength S	On $\frac{1}{2}''$	On $\frac{5}{16}''$	On $\frac{3}{16}''$	Through $\frac{3}{16}''$	Stadler's energy units	Mean total	S_2	Stadler, standard =1·69
C 14	431	29	16	27	−3	669	701	0·961	0·72	0·21	0·18	0·65	1·76	1·89	0·92	0·89
	400	48	20	32	0	732			0·66	0·35	0·23	0·77	2·01			
C 15	395	44	21	37	3	762	759	0·888	0·66	0·32	0·24	0·89	2·11	2·14	0·79	0·79
	397	44	20	40	−1	756			0·66	0·32	0·23	0·96	2·17			
C 16	419	37	20	25	−1	684	693	0·973	0·70	0·27	0·23	0·60	1·80	1·83	0·95	0·92
	420	33	17	30	0	701			0·70	0·24	0·20	0·72	1·86			
C 81	303	67	43	88	−1	1039	1039	0·649	0·50	0·49	0·50	2·11	3·60	3·60	0·42	0·47
C 82	324	60	33	84	−1	993	993	0·679	0·54	0·44	0·38	2·01	3·37	3·37	0·46	0·50
C 83	362	54	30	56	−2	852	894	0·754	0·60	0·40	0·35	1·34	2·69	2·85	0·57	0·59
	332	66	34	66	2	936			0·55	0·49	0·39	1·58	3·01			
C 86	426	23	17	36	−2	708	708	0·952	0·71	0·17	0·20	0·86	1·94	1·94	0·91	0·87
C 87	360	52	31	53	4	865	865	0·780	0·60	0·38	0·36	1·27	2·61	2·61	0·61	0·65
C 88	399	52	19	31	−1	725	727	0·928	0·66	0·38	0·22	0·74	2·00	2·03	0·86	0·83
	413	32	20	37	−2	729			0·69	0·24	0·23	0·89	2·05			
C 89	402	40	22	37	−1	745	796	0·847	0·67	0·29	0·25	0·89	2·10	2·43	0·72	0·70
	336	89	32	49	−6	846			0·56	0·65	0·37	1·18	2·76			
C 97	378	57	22	43	0	790	784	0·860	0·63	0·42	0·25	1·03	2·33	2·30	0·74	0·73
	394	39	23	44	0	778			0·65	0·29	0·26	1·06	2·26			
C 98	380	64	27	50	−1	836	836	0·807	0·63	0·47	0·31	1·20	2·61	2·61	0·65	0·65
C 113	427	35	20	17	1	656	650	1·037	0·71	0·26	0·23	0·41	1·61	1·61	1·08	1·05
	429	36	18	17	0	649			0·71	0·27	0·21	0·41	1·60			
	426	39	21	16	−2	645			0·71	0·29	0·24	0·38	1·62			
C 114	438	29	17	17	−1	635	654	1·030	0·73	0·21	0·20	0·41	1·55	1·64	1·06	1·03
	426	38	16	21	−1	660			0·71	0·28	0·18	0·50	1·67			
	426	36	17	22	−1	664			0·71	0·27	0·20	0·53	1·71			
C 115	430	25	17	31	−3	684	706	0·954	0·71	0·18	0·20	0·74	1·83	1·94	0·91	0·87
	420	26	17	39	−2	724			0·70	0·19	0·20	0·94	2·03			
	417	37	14	35	−3	709			0·69	0·27	0·16	0·84	1·96			
C 116	432	25	18	24	−1	671	674	1·000	0·72	0 18	0·21	0·58	1·69	1·72	1·00	0·98
	422	30	20	28	0	696			0·70	0·22	0·23	0·67	1·82			
	426	42	11	21	0	656			0·71	0·31	0·13	0·50	1·65			
C 117	337	48	35	82	−2	971	979	0·689	0·56	0·35	0·40	1·97	3·28	3·26	0·47	0·52
	325	51	43	79	2	996			0·54	0·38	0·50	1·89	3·31			
	338	47	35	79	1	970			0·56	0·35	0·40	1·89	3·20			
C 118	362	47	25	65	1	888	911	0·740	0·60	0·35	0·29	1·56	2·80	2·95	0·55	0·57
	316	87	29	72	−4	945			0·52	0·64	0·33	1·73	3·22			
	367	37	25	69	2	899			0·61	0·27	0·29	1·65	2·82			

TABLE VI—Continued

Coke Number	Weight on ½″ = grams	Weight on 5/16″ = grams	Weight on 3/16″ = grams	Weight through 3/16″ = grams	Weight lost grams	Factor	Mean factor	Relative strength S	On ½″	On 5/16″	On 3/16″	Through 3/16″	Stadler's energy units, total	Mean total	S²	Stadler, standard = 1·69
										Stadler's values for material					Relative strength values.	

SPECIAL COKES—Continued

Coke Number	Weight on ½″	Weight on 5/16″	Weight on 3/16″	Weight through 3/16″	Weight lost	Factor	Mean factor	Relative strength S	On ½″	On 5/16″	On 3/16″	Through 3/16″	Stadler's energy units, total	Mean total	S²	Stadler, standard = 1·69
C 119	421	33	18	28	0	695	688	0·980	0·70	0·24	0·21	0 67	1·82	1·81	0·96	0·93
	428	26	16	32	−2	691			0·71	0·19	0·18	0·77	1·85			
	424	37	13	27	−1	679			0·70	0·27	0·15	0·65	1·77			
C 120	334	89	30	49	−2	857	864	0·780	0·55	0·65	0·35	1·18	2·73	2·74	0·61	0·62
	338	76	36	51	−1	870			0·56	0·56	0·41	1·22	2·75			
C 121	347	67	31	51	4	872	852	0·791	0·58	0·49	0·36	1·22	2·65	2·57	0·63	0·66
	370	55	22	51	2	831			0·61	0·40	0·25	1·22	2·48			
C 122	327	74	37	63	−1	918	925	0·729	0·54	0·54	0·43	1·51	3·02	3·05	0·53	0·55
	349	51	39	62	−1	899			0·58	0·38	0·45	1·49	2·90			
	330	57	40	75	−2	959			0·55	0·42	0·46	1·80	3·23			
C 123	365	64	28	45	−2	811	811	0·830	0·61	0·47	0·32	1·08	2·48	2·45	0·69	0·69
	350	77	30	44	−1	828			0·58	0·57	0·35	1·06	2·56			
	381	48	28	42	1	795			0·63	0·35	0·32	1·01	2·31			
C 35D	409	37	20	35	−1	729	729	0·925	0·68	0·27	0·23	0·84	2·02	2·02	0·86	0·84
C 1/23M+31	296	79	43	83	−1	1032	1024	0·659	0·49	0·58	0·50	1·99	3·56	3·49	0·43	0·48
	308	68	42	80	2	1015			0·51	0·50	0·48	1·92	3·41			
C 1/23M+26	260	75	43	121	1	1195	1159	0·582	0·43	0·55	0·50	2·90	4·38	4·22	0·34	0·40
	268	86	44	103	−1	1122			0·44	0·63	0·51	2·47	4·05			
C 1/23M+ D.I.&S.Co.	242	87	55	115	1	1209	1209	0·558	0·40	0·64	0·63	2·76	4·43	4·43	0·31	0·38
C 1/25+20	296	73	46	82	3	1042	1042	0·645	0·49	0·54	0·53	1·97	3·53	3·53	0·42	0·48
C1/40A+31	324	47	39	90	0	1023	1023	0·659	0·54	0·35	0·45	2·16	3·50	3·50	0·43	0·48

WORK OF THE CHEMICAL LABORATORY

BY
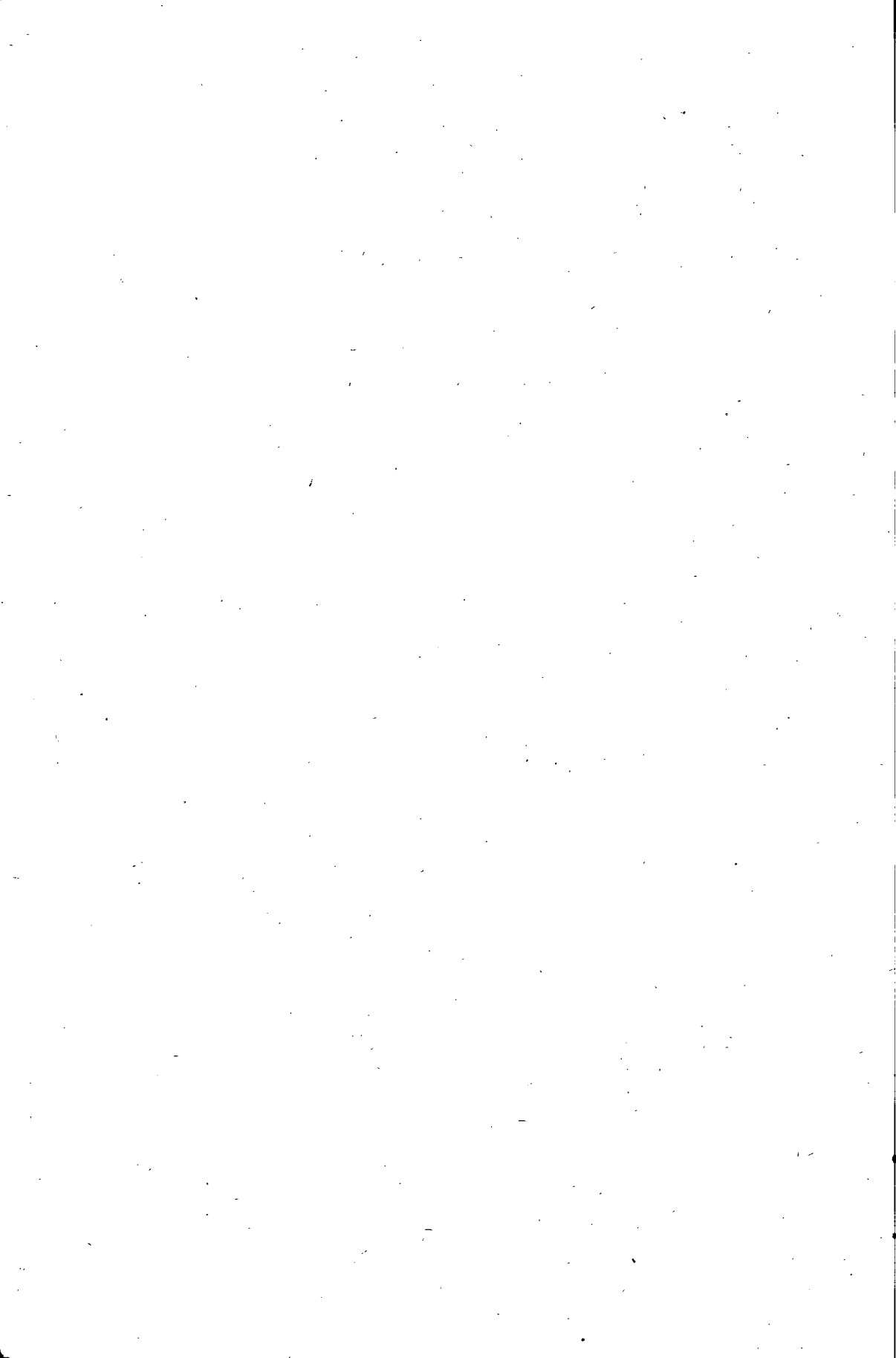
EDGAR STANSFIELD

TABLE VII

AVERAGE ANALYSES OF REGULAR COAL SAMPLES IN COAL FIELDS INVESTIGATED

	Sydney, Cape Breton county, N.S.	Inverness county, Nova Scotia	Pictou, Pictou county, Nova Scotia	Springhill, Cumberland county, Nova Scotia	Joggins, Chignecto, Cumberland county, N.S.	Grand Lake, Queens county, New Brunswick	Souris, Saskatchewan	Edmonton, Alberta	Belly river, Alberta	Frank Blairmore, Alberta	Crowsnest, British Columbia	Cascade, Alberta	Similkameen, British Columbia	Nicola valley, British Columbia	Nanaimo-Comox, Vancouver island, B.C.	Alert bay, Vancouver island, B.C.	Whitehorse, Yukon Territory
1. Coal-field............																	
2. Number of samples included in average........	9	2	6	3	3	1	2	3	3	6	8	4	3	2	5	1	3
Moisture in coal																	
3. Total moisture...............................%	3·7	7·0	2·4	2·6	2·9	1·3	29·7	22·9	8·8	1·9	2·3	1·5	2·6	3·7	2·1	7·0	....
4. Moisture left after air drying.... ....%	2·6	5·3	1·7	2·1	2·2	0·9	18·1	19·0	7·8	0·8	0·9	0·7	....	3·1	1·5		....
Proximate analysis of dry coal																	
5. Fixed carbon (FC) by difference............%	56·3	49·0	57·5	59·0	46·4	53·4	43·1	49·6	47·2	56·8	64·2	71·6	53·2	47·2	52·3	42·7	56·0
6. Volatile matter (VM)......................%	36·4	38·5	29·6	33·0	37·8	32·2	44·5	40·3	34·5	26·3	24·6	14·7	32·7	39·1	36·5	34·3	26·5
7. Ash......................................%	7·3	12·5	12·9	8·0	15·8	14·4	12·4	10·1	18·3	16·9	11·2	13·7	14·1	13·7	11·2	23·0	17·5
Ultimate analysis of dry coal																	
8. Carbon (C)................................%	75·8	65·4	73·0	76·6	64·8	70·3	58·7	64·6	61·9	70·7	76·8	76·6	70·4	68·3	72·3	....	70·4
9. Hydrogen (H)..............................%	5·1	4·5	4·5	4·9	4·4	4·6	4·6	4·5	4·6	4·2	4·5	3·7	4·5	5·0	4·6	....	4·2
10. Sulphur....................................%	2·9	6·9	1·2	1·5	6·2	5·8	0·6	0·4	1·1	0·6	0·5	0·6	1·9	0·8	0·9	....	0·5
11. Nitrogen....................................%	1·4	0·9	1·9	1·6	1·2	0·6	1·0	1·3	1·6	1·0	1·2	1·1	....	1·6	1·1	....	0·8
12. Oxygen, by difference......................%	7·5	9·8	6·5	7·4	7·6	4·3	22·7	19·1	12·5	6·6	5·8	4·3	....	10·6	9·9	....	7·6
Calorific value of dry coal																	
13. By determination...................calories	7590	6650	7210	7510	6590	7160	5650	6110	6030	6830	7440	7270	....	6620	7150	6170	6600
14. " " ..........B.T.U.	13660	11960	12970	13520	11860	12890	10170	11000	10850	12300	13400	13080	....	11920	12870	11100	11880
15. " " calculated to ash free coal calories	8190	7600	8280	8170	7830	8360	6460	6800	7400	8220	8380	8420	....	7670	8050	8010	8000
16. By calculation from ultimate analysis...calories	7620	6580	7180	7580	6590	7220	5350	5980	6070	6890	7520	7290	....	6830	7010	....	6810
17. Ratio FC/VM..............................	1·55	1·27	1·94	1·79	1·23	1·66	0·97	1·23	1·37	2·16	2·61	4·87	1·62	1·21	1·43	1·24	2·12
18. Ratio C/H................................	14·9	14·5	16·2	15·6	14·7	15·3	12·8	14·3	13·5	16·8	17·1	20·7	15·6	13·6	15·7		16·8

APPENDIX V

WORK OF THE CHEMICAL LABORATORY

BY

EDGAR STANSFIELD

Average Analyses of Regular Coal Samples in Coal Fields Investigated.

In order to show clearly the type of coal to be found in each of the coal fields investigated, Table VII has been compiled showing the average analysis for each field. Only the regular samples were included in the averages; to have done otherwise would have given undue weight to those seams or collieries from which more than one sample was obtained; the figures for moisture were, however, taken from the mine moisture sample.

Coal Classifications.

In Tables VIII, IX, and X are given, for all the regular coals tested, the values calculated for some of the better known coal classification ratios, together with the determined calorific value of the dry coal.

The first column gives the reference number of the coal.

The second column gives the calorific value of the dry coal in calories per gram, as determined by means of the F. Köhler bomb calorimeter.

The third column gives the carbon-hydrogen ratio in the dry coal, calculated from the ultimate analysis of the coal, which was made upon the dry sample.

The fourth column gives the carbon-hydrogen ratio in air dry coal; this is calculated from the ultimate analysis of the dry coal, allowing for the hydrogen and oxygen in the moisture contained in the air dry coal (this moisture determination was made on the mine moisture sample). M. R. Campbell[1] recommends the carbon-hydrogen ratio as the most satisfactory basis for the classification of coals. His analyses were made on air dry samples, while those of this report were made on dry samples. These tables show the amount of difference caused in the ratio.

The fifth column gives the well-known fuel ratio, that is, fixed carbon divided by volatile matter. This is a classification depending on the proximate analysis of the coal; it obviously is not affected by the moisture content of the sample.

The sixth column gives a ratio suggested by D. B. Dowling.[2] This ratio is fixed carbon plus one-half the volatile matter, divided by moisture plus one-half the volatile matter, the analyses being made on the air dry

[1] U.S. Geol. Survey, Prof. Paper 48 (1906), pp. 156-173.
[2] Report No. 1035 of the Geol. Survey Branch of the Department of Mines, Canada, p. 43. See also Canadian Mining Journal, Vol. XXIX, p. 143, 1908.

sample. Actually the analyses were made on the dry sample and calculated to air dry by allowing for the moisture found in the air dry, mine moisture sample.

The seventh column (omitted in Table X) gives the ratio of carbon divided by oxygen plus ash; this is a ratio employed by D. White.[1] It is worth noting that although, as has been discussed elsewhere, the oxygen and ash of a coal analysis are conventional terms, only approximating to definite constituents of the original coal, yet oxygen plus ash has a very definite value and significance, if it is regarded as that part of the coal which is not carbon, hydrogen, nitrogen, or sulphur.

In Table VIII the coals are arranged in geographical order and subdivided into the different coal fields. In Table IX the coals are arranged in order of the calorific values; for comparison with the split volatile ratio it would probably have been better to recalculate the calorific value to the air dry basis. In Table X the coals are arranged in order of the carbon-hydrogen ratio of the dry coal.

TABLE VIII
COAL CLASSIFICATIONS
Coals arranged in geographical order

Coal-field.	Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O+ Ash.
Sydney, N.S..........	36	7700	15·3	14·5	1·58	3·6	5·4
	35	7780	14·8	14·3	1·44	3·6	6·1
	35 SP.	7800	14·8	14·3	1·70	4·0	6·1
	38	7780	15·4	14·8	1·74	4·0	6·1
	37	7290	14·9	14·3	1·53	3·6	4·0
	39	7660	14·9	13·8	1·55	3·4	5·6
	13	7650	14·8	14·0	1·48	3·5	4·9
	12	7600	14·7	13·5	1·39	3·1	4·7
Inverness, N.S........	14	6750	14·0	11·8	1·24	2·5	3·2
	15	6540	15·1	13·9	1·30	3·1	2·7
Pictou, N.S...........	4	6680	16·2	15·3	1·57	3·7	2·7
	16	7350	16·1	15·4	1·66	3·9	3·9
	1	6990	15·8	....	1·86	....	3·4
	2	7320	16·5	15·8	1·85	4·2	4·1
	8	7700	16·5	15·9	2·49	5·3	5·1
	3	7200	16·9	16·4	2·46	5·4	3·9
Springhill, N.S........	5	7430	15·3	14·7	1·81	4·1	4·4
	6	7220	15·9	15·0	1·64	3·8	3·9
	49	7880	16·0	....	1·90	....	7·8
Joggins-Chignecto, N.S.	7	6750	13·8	12·8	1·11	2·8	3·1
	9	6570	14·7	13·7	1·37	3·2	2·8
	10	6440	15·5	15·2	1·22	3·3	2·5
Grand Lake, N.B......	11	7160	15·3	15·0	1·66	4·1	3·8

[1] P. 8, etc., Bulletin 382, U.S. Geol. Survey.

TABLE VIII—Continued

Coal-field.	Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O+ ash.
Souris, Sask..........	40	5940	12·5	8·2	0·88	1·5	1·8
	41	5360	13·4	8·2	1·08	1·5	1·6
Edmonton, Alta.......	46	5960	14·0	9·0	1·16	1·6	2·0
	42	6060	14·2	9·1	1·36	1·7	2·3
	45	6310	14·6	9·1	1·19	1·6	2·3
Belly river, Alta.......	43	6130	13·7	10·4	1·39	2·2	2·3
	44	6510	13·6	11·4	1·37	2·6	2·5
	47	5450	13·4	12·1	1·33	2·9	1·4
Frank-Blairmore, Alta..	48	6800	15·9	15·7	2·04	4·7	2·9
	32	6920	16·7	16·2	1·89	4·4	3·0
	33	6880	16·6	16·6	2·06	5·1	3·2
	28	6930	16·9	16·6	2·34	5·3	3·1
	34	6510	17·1	16·8	·2·19	5·1	2·6
	34 SP.	6960	16·9	16·6	2·51	5·7	3·4
Crowsnest, B.C........	31	7370	17·5	17·4	2·53	5·9	4·1
	30	7420	17·0	16·8	2·90	6·4	4·4
	29	7490	16·9	16·5	2·72	5·9	4·4
	51	7060	17·7	17·3	2·98	....	3·7
	52	7270	16·9	16·4	2·42	....	4·3
	53	7770	15·6	15·2	2·30	....	6·1
	27	7680	18·0	17·5	2·46	5·4	5·4
	26	7490	17·5	17·3	2·72	6·2	4·6
Cascade, Alta.........	25	7340	19·6	19·1	4·10	8·3	3·9
	23	7400	22·0	21·7	6·44	12·7	5·2
	23 SP.	7040	20·6	20·3	5·68	11·4	4·0
	23 M.	7270	21·3	....	5·82	....	4·2
	24	7280	20·6	20·1	4·01	8·2	4·1
Similkameen, B.C......	Ex. 1	....	14·9	14·2	1·60	....	....
	Ex. 2	....	15·9	15·4	1·65	....	....
	Ex. 3	....	16·1	14·9	1·61	....	....
Nicola valley, B.C. ...	22	6490	13·4	12·3	1·2	2·8	2·6
	22 SP.	6760	13·6	13·0	1·2	3·1	3·0
	22 M.	6510	13·5	....	1·2	....	2·5
Nanaimo-Comox, B.C..	20	7310	15·5	15·1	1·2	3·3	3·5
	18	7130	15·0	14·5	1·2	3·1	3·4
	17	6930	15·0	14·3	1·1	3·0	2·9
	21	7150	16·5	....	1·8	....	3·5
	21 SP.	7210	16·5	....	2·1	....	3·9
	21 M.	7230	16·7	....	1·9	....	3·6
Alert bay, B.C.	Ex. 34	6170	....	....	1·2	....	....
Whitehorse, Yukon Territory...........	Ex. 31	6700	17·5	....	2·3	....	2·8
	Ex. 32	6310	....	....	2·0	....	....
	Ex. 33	6790	16·5	....	2·0	....	3·0

TABLE IX

COAL CLASSIFICATIONS

Coals arranged in order of calorific value

Coal No.	C. V.	C/H dry	C/H air dried	Fuel ratio.	Split volatile ratio	C/O + Ash
49	7880	16·0	....	1·90	....	7·8
35 SP	7800	14·8	14·3	1·70	4·0	6·1
38	7780	15·4	14·8	1·74	4·0	6·1
35	7780	14·8	14·3	1·44	3·6	6·1
53	7770	15·6	15·2	2·30	....	6·1
36	7700	15·3	14·5	1·58	3·6	5·4
8	7700	16·5	15·9	2·49	5·3	5·1
27	7680	18·0	17·5	2·46	5·4	5·4
39	7660	14·9	13·8	1·55	3·4	5·6
13	7650	14·8	14·0	1·48	3·5	4·9
12	7600	14·7	13·5	1·39	3·1	4·7
29	7490	16·9	16·5	2·72	5·9	4·4
26	7490	17·5	17·3	2·72	6·2	4·6
5	7430	15·3	14·7	1·81	4·1	4·4
30	7420	17·0	16·8	2·90	6·4	4·4
23	7400	22·0	21·7	6·44	12·7	5·2
31	7370	17·5	17·4	2·53	5·9	4·1
16	7350	16·1	15·4	1·66	3·9	3·9
25	7340	19·6	19·1	4·10	8·3	3·9
2	7320	16·5	15·8	1·85	4·2	4·1
20	7310	15·5	15·1	1·24	3·3	3·5
37	7290	14·9	14·3	1·53	3·6	4·0
24	7280	20·6	20·1	4·01	8·2	4·1
23 M	7270	21·3	....	5·82	....	4·2
52	7270	16·9	16·4	2·42	....	4·3
21 M	7230	16·7		1·91	....	3·6
6	7220	15·9	15·0	1·64	3·8	3·9
21 SP	7210	16·5	....	2·14	....	3·9
3	7200	16·9	16·4	2·46	5·4	3·9
11	7160	15·3	15·0	1·66	4·1	3·8
21	7150	16·5	....	1·79	....	3·5
18	7130	15·0	14·5	1·18	3·1	3·4
51	7060	17·7	17·3	2·98	....	3·7
23 SP	7040	20·6	20·3	5·68	11·4	4·0
1	6990	15·8	....	1·86	....	3·4
34 SP	6960	16·9	16·6	2·51	5·7	3·4
28	6930	16·9	16·6	2·34	5·3	3·1
17	6930	15·0	14·3	1·12	3·0	2·9
32	6920	16·7	16·2	1·89	4·4	3·0
33	6880	16·6	16·6	2·06	5·1	3·2
48	6800	15·9	15·7	2·04	4·7	2·9
Ex. 33	6790	16·5	....	2·02	....	3·0
22 SP	6760	13·6	13·0	1·23	3·1	3·0
14	6750	14·0	11·8	1·24	2·5	3·2
7	6750	13·8	12·8	1·11	2·8	3·1
Ex. 31	6700	17·5	....	2·32	....	2·8
4	6680	16·2	15·3	1·57	3·7	2·7
9	6570	14·7	13·7	1·37	3·2	2·8
15	6540	15·1	13·9	1·30	3·1	2·7
34	6510	17·1	16·8	2·19	5·1	2·6
44	6510	13·6	11·4	1·37	2·6	2·5
22 M	6510	13·5	....	1·20	....	2·5
22	6490	13·4	12·3	1·19	2·8	2·6
10	6440	15·5	15·2	1·22	3·3	2·5

TABLE IX—Continued

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O + Ash.
45	6310	14·6	9·0	1·19	1·6	2·3
Ex. 32	6310	....	....	2·03	....	....
Ex. 34	6170	....	....	1·24	....	....
43	6130	13·7	10·4	1·39	2·2	2·3
42	6060	14·2	9·1	1·36	1·7	2·3
46	5960	14·0	9·0	1·16	1·6	2·0
40	5940	12·5	8·2	0·88	1·5	1·8
47	5450	13·4	12·1	1·33	2·9	1·4
41	5360	13·4	8·2	1·08	1·5	1·6

TABLE X

COAL CLASSIFICATIONS

Coals arranged in order of carbon-hydrogen ratio

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.
23	7400	22·0	21·7	6·44	12·7
23 M	7270	21·3	....	5·82	....
23 SP	7040	20·6	20·3	5·68	11·4
24	7280	20·6	20·1	4·01	8·2
25	7340	19·6	19·1	4·10	8·3
27	7680	18·0	17·5	2·46	5·4
51	7060	17·7	17·3	2·98	....
31	7370	17·5	17·4	2·53	5·9
26	7490	17·5	17·3	2·72	6·2
Ex. 31	6700	17·5	....	2·32	....
34	6510	17·1	16·8	2·19	5·1
30	7420	17·0	16·8	2·90	6·4
52	7270	16·9	16·4	2·42	....
29	7490	16·9	16·5	2·72	5·9
34 SP	6960	16·9	16·6	2·51	5·7
28	6930	16·9	16·6	2·34	5·3
3	7200	16·9	16·4	2·46	5·4
32	6920	16·7	16·2	1·89	4·4
21 M	7230	16·7	....	1·91	....
33	6880	16·6	16·6	2·06	5·1
Ex. 33	6790	16·5	....	2·02	....
21 SP	7210	16·5	....	2·14	....
21	7150	16·5	....	1·79	....
8	7700	16·5	15·9	2·49	5·3
2	7320	16·5	15·8	1·85	4·2
4	6680	16·2	15·3	1·57	3·7
16	7350	16·1	15·4	1·66	3·9
Ex. 3	....	16·1	14·9	1·61	....
49	7880	16·0	....	1·90	....
Ex. 2	....	15·9	15·4	1·65	....
48	6800	15·9	15·7	2·04	4·7
6	7220	15·9	15·0	1·64	3·8
1	6990	15·8	....	1·86	....
53	7770	15·6	15·2	2·30	....
20	7310	15·5	15·1	1·24	3·3
10	6440	15·5	15·2	1·22	3·3
38	7780	15·4	14·8	1·74	4·0

TABLE X—Continued

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split vola-tile ratio.
11	7160	15·3	15·0	1·66	4·1
5	7430	15·3	14·7	1·81	4·1
36	7700	15·3	14·5	1·58	3·6
15	6540	15·1	13·9	1·30	3·1
18	7130	15·0	14·5	1·18	3·1
17	6930	15·0	14·3	1·12	3·0
39	7660	14·9	13·8	1·55	3·4
37	7290	14·9	14·3	1·53	3·6
Ex. 1	. . . .	14·9	14·2	1·60	. . . .
35	7780	14·8	14·3	1·44	3·6
35 SP	7800	14·8	14·3	1·70	4·0
13	7650	14·8	14·0	1·48	3·5
12	7600	14·7	13·5	1·39	3·1
9	6570	14·7	13·7	1·37	3·2
45	6310	14·6	9·0	1·19	1·6
42	6060	14·2	9·1	1·36	1·7
46	5960	14·0	9·0	1·16	1·6
14	6750	14·0	11·8	1·24	2·5
7	6750	13·8	12·8	1·11	2·8
43	6130	13·7	10·4	1·39	2·2
44	6510	13·6	11·4	1·37	2·6
22 SP	6760	13·6	13·0	1·23	3·1
22 M	6510	13·5	. . . .	1·20	. . . .
22	6490	13·4	12·3	1·19	2·8
41	5360	13·4	8·2	1·08	1·5
47	5450	13·4	12·1	1·33	2·9
40	5490	12·5	8·2	0·88	1·5

Comparison of Determined and Calculated Calorific Values.

In Table XI is given the determined calorific values of all regular coal samples together with the calorific values calculated both from the ultimate and from the proximate analyses of these samples.

The coals are arranged geographically and classified into the different fields; the reference number of the sample is given in the first column.

The second column gives the determined calorific value of the dry coal, expressed in calories per gram.

The third column gives the calorific value calculated from the ultimate analysis by means of Dulong's formula.

$80 \cdot 8\ C + 344 \cdot 6\ (H - \frac{1}{8}O) + 22 \cdot 5\ S =$ calorific value in calories per gram—where C, H, O, and S stand for the percentages of carbon, hydrogen, oxygen and sulphur, respectively, in the sample.

The fourth column gives the difference between the values in the third column and the determined calorific value. At the foot of the column these differences are averaged in two ways ; firstly, the arithmetic average in which the numbers are considered as such and difference of sign not considered; secondly, the algebraic average in which difference of sign is taken into account.

TABLE XI

COMPARISON OF DETERMINED AND CALCULATED CALORIFIC VALUES

Coal-field.	Coal No.	Determined C.V.	Calc. C.V. by Dulong's formula.	Difference.	Calc. C.V. by Goutal's formula.	Difference.
Sydney, N.S............	50	7010	7290	+280	7160	+150
	36	7700	7600	−100	7730	+ 30
	35	7780	7830	+ 50	7600	−180
	35 SP.	7800	7920	+120	7960	+160
	38	7780	7850	+ 70	7970	+190
	37	7290	7360	+ 70	7250	− 40
	39	7660	7720	+ 60	7790	+130
	13	7650	7570	− 80	7630	− 20
	12	7600	7450	−150	....	....
Inverness, N.S..........	14	6750	6770	+ 20	....	....
	15	6540	6390	−150	....	....
Pictou, N.S............	4	6680	6620	− 60	6800	+120
	16	7350	7280	− 70	7420	+ 70
	1	6990	7080	+ 90	7350	+360
	2	7320	7220	−100	7710	+390
	8	7700	7670	− 30	7910	+210
	3	7200	7230	+ 30	7430	+230
Springhill, N.S..........	5	7430	7450	+ 20	7780	+350
	49	7880	8060	+180	8340	+460
	6	7220	7220	0	7370	+150
Joggins-Chignecto, N.S...	7	6750	6810	+ 60	....	....
	9	6570	6590	+ 20	....	....
	10	6440	6360	− 80	....	....
Grand Lake, N.B........	11	7160	7220	+ 60	7170	+ 10
Souris, Sask...........	40	5940	5400	−540	....	....
	41	5360	5290	− 70	....	....
Edmonton, Alta.........	46	5960	5820	−140	....	....
	42	6060	6110	+ 50	....	....
	45	6310	6000	−310	....	....
Belly river, Alta.........	43	6130	6280	+150	....	....
	44	6510	6430	− 80	....	....
	47	5450	5490	+ 40	....	....
Frank-Blairmore, Alta....	48	6800	6910	+110	7110	+310
	32	6920	6770	−150	7310	+390
	33	6880	6970	+ 90	7320	+440
	28	6930	6940	+ 10	7250	+320
	34	6510	6650	+140	6950	+440
	34 SP.	6960	7120	+160	7290	+330
Crowsnest, B.C..........	31	7370	7350	− 20	7620	+250
	30	7420	7500	+ 80	7690	+270
	29	7490	7400	− 90	7630	+140
	51	7060	7260	+200	7390	+330
	52	7270	7460	+190	7540	+270
	53	7770	7980	+210	8040	+270
	27	7680	7690	+ 10	7910	+230
	26	7490	7520	+ 30	7770	+280

TABLE XI—Continued

Coal-field.	Coal No.	Deter-mined C.V.	C.V. calc. by Dulong's formula.	Differ-ence.	C.V. calc. by Goutal's formula.	Differ-ence.
Cascade, B.C...........	25	7340	7040	−300	7660	+320
	23	7400	7530	+130	7660	+260
	23 SP	7040	7290	+250	7330	+290
	23 M	7270	7300	+ 30	7490	+220
	24	7280	7280	0	7480	+200
Similkameen, B.C........	Ex. 1	....	....	....	7260	....
	Ex. 2	....	....	....	7180	....
	Ex. 3	....	....	....	6965	....
Nicola valley, B.C........	22	6490	6690	+200	....	....
	22 SP	6760	6970	+210	....	....
	22 M	6510	6500	− 10	....	....
Nanaimo-Comox, B.C....	20	7310	7040	−270	....	....
	18	7130	7020	−110	....	....
	17	6930	6680	−250	....	....
	21	7150	7050	−100	7510	+360
	21 SP	7210	7270	+ 60	7650	+440
	21 M	7230	7120	−110	7600	+370
Alert bay, B.C..	Ex. 34	6170	....	....	....	....
Whitehorse, Yukon Ter-ritory................	Ex. 31	6700	6690	− 10	7200	+ 500
	Ex. 32	6310	....	....	7310	+1000
	Ex. 33	6790	6930	+140	7250	+ 460
Average error:—						
Arithmetic.......				+113	....	+278
Algebraic........				+ 4	....	+267

The fifth column gives the calorific values calculated from the proximate analysis by means of Goutal's formula.[1] The percentage of volatile matter is first recalculated to percentage of pure fuel (fixed carbon+volatile matter), then the calorific value calculated by multiplying the percentage of fixed carbon in the fuel by 82 and adding to the result the product obtained by multiplying the percentage of volatile matter *in the fuel* by a factor which varies, as shown below, with the percentage of volatile matter *in the pure fuel.*

% V.M. in pure fuel........	5	6	7	8	9	10	11	12	13	14
Factor....................	145	142	139	136	133	130	127	124	122	120
% V.M. in pure fuel........	15	16	17	18	19	20	21	22	23	24
Factor....................	117	115	113	112	110	109	108	107	105	104
% V.M. in pure fuel........	25	26	27	28	29	30	31	32	33	34
Factor....................	103	102	101	100	99	98	97	97	96	95
% V.M. in pure fuel........	35	36	37	38	39	40				
Factor....................	94	91	88	85	82	80				

[1] Goutal, Journal für Gasbeleuchtung, 1905, Vol. 48, p. 1007, Abstr. Electrochemical and Metallurgical Industry, 1907, Vol. 5, p. 145.

For example, coal 50 *analysis*, fixed carbon $53\cdot0\%$, volatile matter $34\cdot7\%$, ash $12\cdot3\%$. Volatile matter in pure fuel $= 34\cdot7\times\frac{100}{53\cdot0\,+\,34\cdot7}=$ $39\cdot6$, therefore the factor for volatile matter is 81, and the calorific value in calories per gram is $(53\cdot0\times82)+(34\cdot7\times81)=4346+2811=7157$.

The last column gives the difference between the values in the fifth column and the determined calorific value. Arithmetical and algebraic averages of these differences are given at the foot of the column.

It is impossible to calculate the calorific values of some Canadian coals by this formula, since the volatile matter in many samples is higher than is provided for in Goutal's formula. A satisfactory formula for even roughly approximating the calorific value of a fuel from its proximate analysis would be very useful, but the differences shown by the table for Goutal's formula are discouragingly large, even within the limits which he himself has set.

Variations in Weight of Samples Stored in Closed Cans.

The sample cans tested were similar to those used throughout the whole investigation for shipping or storing samples; they are described in Vol. II, p. 125.

A sample of coal No. 14, crushed to $\frac{1}{8}''$ size and air dried, was used for the tests. Can A was weighed empty; filled with the coal and again weighed; the contents of the can were sprinkled with water, the can closed as usual, and weighed for the last time. Sufficient coal to fill can B was spread out on a couple of trays and dried in an oven for several hours and the loss of weight determined; the dry coal was then put into the can which was closed and weighed.

The two cans were placed in their outer cans and set aside, in order to determine how fast, if at all, the damp coal lost moisture and the dry coal gained it. The cans were re-weighed at intervals for nearly four years.

The portion of coal that was dried lost 7 per cent of moisture, that is to say $107\cdot5$ grams of the original sample contain 100 grams of dry coal; $1015\cdot5$ grams of the original sample had been put into can A and $975\cdot5$ grams into can B.

Table XII shows the changes in weight of the contents of the cans, in order to make these clearer the weights have been re-calculated to the basis of 100 grams of dry coal; Fig. 1 shows the same thing in graphic form. It is quite certain from this test that the sample cans do nor preserve the moisture in their contents entirely unchanged; it is, however, impossible to say how much moisture was gained or lost as the coal was apparently absorbing oxygen with noteworthy rapidity. This is clearly shown in the curve for the damp coal; this loses weight at first owing to the comparatively rapid loss of moisture, but afterwards it gains in weight and ultimately becomes heavier than at the beginning, a change which can only be explained by assuming the oxidation of the coal; the sample had been crushed to the size used for the test about eight months before.
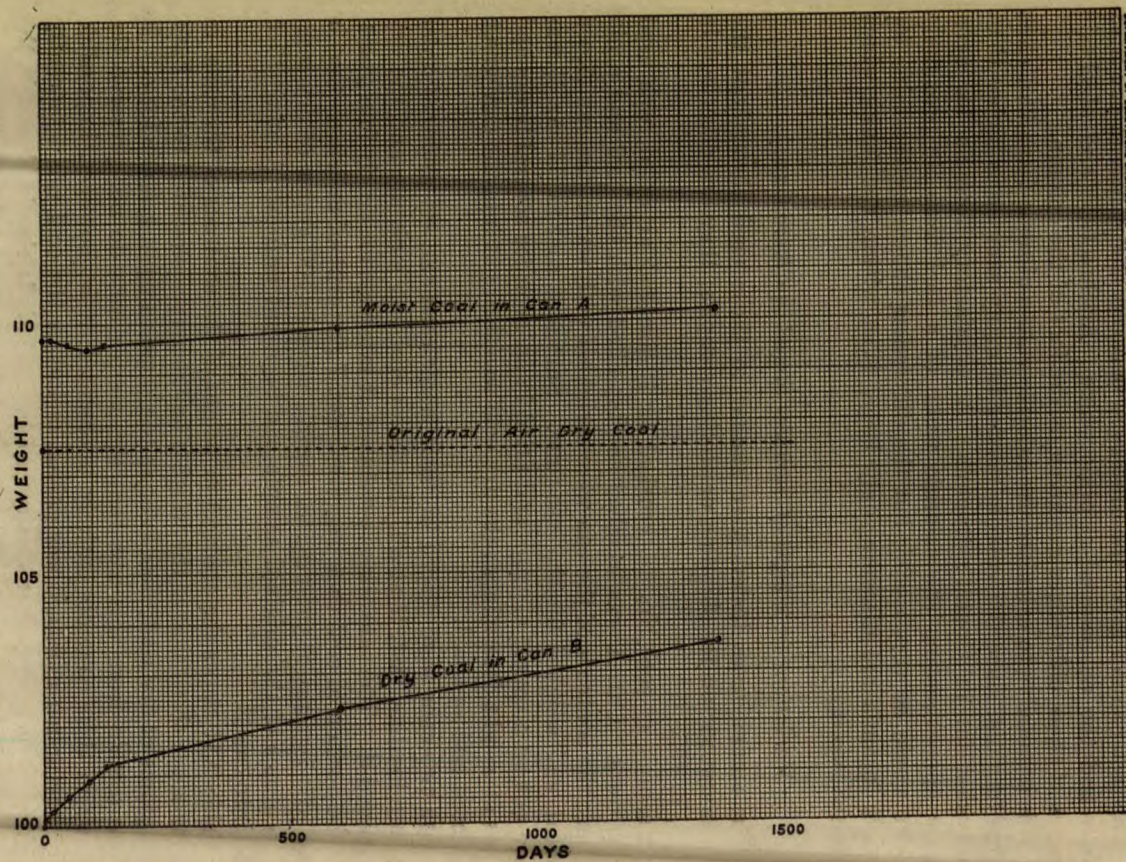
Fig. 1. DIAGRAM SHOWING VARIATIONS IN WEIGHT OF COAL IN CANS

TABLE XII

VARIATIONS IN WEIGHT OF COAL IN CANS.

	Date	Days elapsed	Moist coal in can A	Dry coal in can B
Air dry coal taken....	1-iv-08.......	....	.....107·5	107·5
Coal after moistening	....	....	109·7	....
Coal after drying.....	....	....	....	100·0
Coal stored in can....	1-iv-08.......	0	109·7	....
	2-iv-08......	1	....	100·1
	16-iv-08......	15	109·7	100·3
	21-v-08........	50	109·6	100·6
	30-vi-08......	90	109·5	100·9
	5-viii-08......	126	109·6	101·2
	19-xi-09......	598	109·9	102·3
	30-xii-11..	1368	110·2	103·6

Sampling Losses and Coal Dust.

In order to obtain some idea of the quantity of coal lost as dust or in other ways when a large consignment is sampled, and the possible effect of such loss on the final sample, a careful record was kept whilst two coals were being sampled of the weights of the original consignments and also of all portions cut out; samples of the dust produced whilst sampling one of these coals were also collected and analysed.

The process of sampling has already been described (see Vol. II, p. 123), the dust samples were collected on sheets of paper spread out for the purpose either in the sampling room or outside the building near the orifice of the pipe from the fan used to ventilate the room during the operations of crushing or sampling coal.

Coal No. 35 weighed 9,300 pounds to begin with, it was crushed and sampled down to a sample of about 70 pounds weight which had passed through a $\frac{1}{4}''$ screen; the total loss in all the stages amounted to 62 pounds.

The final sample contained 5·9 per cent of ash. Dust samples were collected which contained percentages of ash as shown below:—

Taken inside whilst the original coal was passed
   through a 3″ bar screen................... 12·3%
Taken at the same time from near fan orifice
   outside............................. 11·2%
Taken inside under fan hopper during crushing
   operations......................... 11·9%
Taken outside near fan orifice during crushing
   operations......................... 10·5%

Coal No. 36 weighed 8 tons, the total loss during sampling amounted to 104 pounds.

Mr. C. Landry was in charge of the sampling operations and collected the dust samples.

Hot Air Oven.

Fig. 2 shows the general construction of the drying oven, a short description of which is given in Part IX, Vol. II, page 132. The figure shows the way in which the products of combustion of the gas used to heat the oven are entirely prevented from entering the oven; it also shows the way in which, by means of double shelves, the heated air rising up through the oven is caused to pass over the surface of any trays placed on the shelves.

Hot Air Oven.
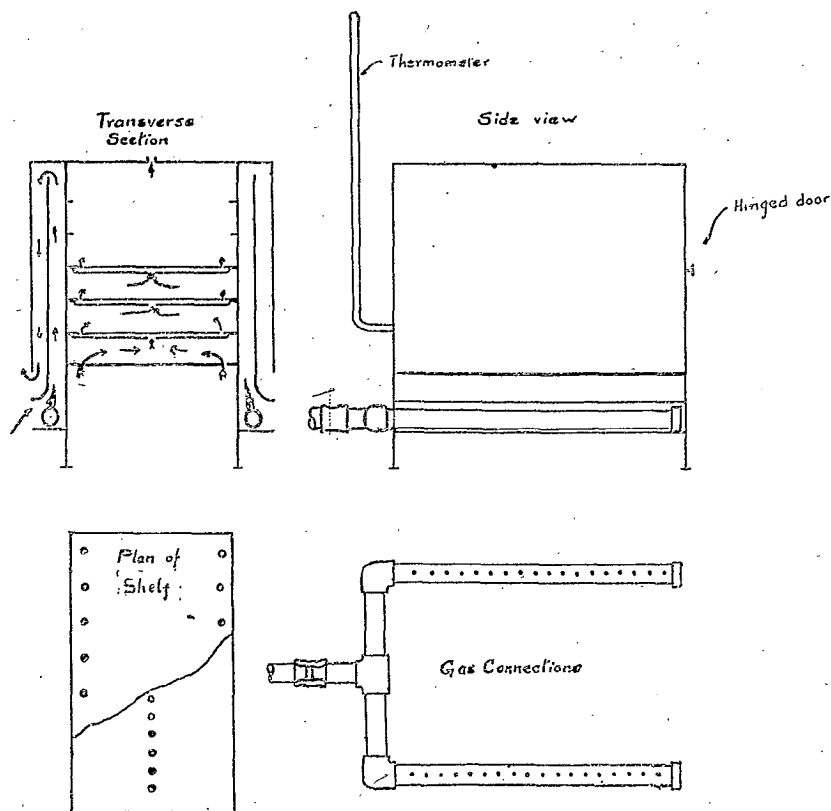
Fig. 2. ILLUSTRATION OF HOT AIR OVEN

Weathering Tests of Coal

This subject was not included in the coal tests investigation as originally outlined, but, on account of its importance, an attempt was made to obtain certain information. When a coal seam is first discovered on the

surface, only outcrop samples are as a rule available; it is well known that such samples differ materially from the main body of the seam which has not been exposed to weathering, but the course of such weathering is not sufficiently well known to enable the nature of the unweathered coal to be predicted at all safely from analyses of the weathered coal, and it is this information which is urgently required.

Samples of coals of different degrees of weathering were obtained from six different seams, and a scheme was drawn up according to which the samples were to be tested. The pressure of routine work, however, was too great to allow this scheme to be carried out in its entirety, or with the promptness which is so desirable in work of this nature. The work done was nevertheless considerable, and although it is not sufficiently complete to render it possible or desirable to draw general conclusions at this time, it will doubtless be of value in conjunction with other work that has been, or may be, done on the subject.

The scheme, which was also intended to throw light on the changes which the coal samples undergo when stored in the laboratory, is as follows: the samples are to be weighed as received and re-weighed when the bottles or cans are opened, the contents are to be crushed in a crusher, ground in a ball mill, thoroughly mixed and riffled down, and divided into the following four lots:—

Lot A.—2 large and 10 small sample tubes to be filled full, and 3 small tubes to be one-fourth filled with the raw coal; these tubes to be labelled Ex. .... (raw), where Ex. .... is the number of the original sample.

Lot B. 50 to 100 grams to be dried for one hour on a tray in an oven at 105° C., 2 large and 10 small sample tubes to be filled full, and 5 small tubes to be one-fourth filled with the dried coal. These tubes are to be labelled Ex. .... (dry).

Lot C. 200–300 grams of the coal to be placed in a tray and weighed and stirred at intervals for six months or more, the trays being kept in a dust-free box exposed to air. This was called Ex. .... (special).

Lot D. A bottle was filled with the remainder, dated with the day of grinding, and stored away labelled Ex. .... (reserve).

The following analyses to be made on the different portions:—

Lot A. Moisture and ash to be determined at once and also an ultimate analysis to be made; moisture to be redetermined at three month intervals and also ultimate analyses made later.

Lot B. Complete analysis to be made at once and also six months later.

Lot C. Sample to be removed from tray from time to time for ultimate analysis, the tray to be weighed each time before and after the sample was removed in order that subsequent changes in weight could be calculated to percentages of original coal.

Table XIII shows the weights of coal in the trays from time to time; these are calculated to the basis of 100 parts of the original coal. Corrections have been made for the weights removed when samples were taken.

Tables XIV to XIX give the results of all analyses. Lines 4 and 5 give the percentage of moisture in the coal. All other analyses are reported upon dry coal in order that they may be comparable; to increase readiness of comparison, analyses are also reported corrected to dry and ash free coal. In all cases where it is of any moment, it is clearly indicated whether the analysis from which a figure is obtained was made upon a raw or a dried sample.

All actual determinations, corrected for moisture if necessary, are indicated by the addition, enclosed in brackets, of the date on which the determination was made; no deduced values have dates attached. No moisture determinations were made on the Ex. .... (special) samples taken from the trays on April 3, 1909, the moisture in these samples is calculated from that found two months later, by assuming that the change in weight in the trays in the meanwhile was entirely due to gain in moisture. Ash was determined in the Ex. .... (raw) samples, in the dry coal left from the moisture determinations; this was assumed to also give the ash in the corresponding Ex. .. (dry) sample. In the same way it is obvious that no serious error has been made by assuming that Ex.... (raw) and Ex..... (special) have the same sulphur and nitrogen content in the dry coal as was found in the corresponding Ex.... (dry) sample.

Ultimate analyses on Ex.... (raw) and Ex.... (dry), instead of being made promptly as intended, were unavoidably delayed for about 8 months. It is almost certain that by the time these analyses were made the raw samples had lost moisture—unless they were already in an air dry condition—and the dry samples had taken up moisture. The ultimate analyses on Ex..... (special) are less open to criticism. Discrepancies between the ultimate analyses of these three sets of samples indicate fairly clearly the probable magnitude of the error in moisture content.

TABLE XIII

WEATHERING TESTS OF COAL

Ground coals exposed in trays on July 17, 1908.

Sample number	Ex.27	Ex. 28	Ex. 16	Ex. 15	Ex. 18	Ex. 17	Ex. 19	Ex. 20	Ex. 21	Ex. 23	Ex. 22	Ex. 25	Ex. 26	Ex. 24
Weight of original coal in tray.......grams	351·3	353·5	44·7	233·5	79·5	94·4	93·2	108·3	87·3	75·3	77·5	28·3	210·4	48·1
Weight of coal at different dates corrected to 100 parts of original coal—														
August 4, 1908 Days elapsed 18....	99·2	97·8	100·2	100·0	100·1	99·8	100·2	99·8	100·2	100·3	99·9	101·1	100·6	89·4
August 15 " " 29....	99·4	98·1	100·1	100·4	100·3	99·9	99·9	99·7	99·9	100·0	99·5	100·7	100·7	89·4
September 9 " " 54....	98·6	97·1	100·1	99·8	100·3	99·7	100·2	99·7	100·0	100·5	100·0	101·4	100·3	88·3
October 2 " " 77....	98·8	97·0	100·0	99·8	100·0	99·4	99·9	99·6	99·7	100·0	99·5	100·4	100·5	87·5
February 23, 1909 " " 221....	98·1	93·4	99·6	95·9	100·0	97·8	99·7	99·3	98·7	99·9	99·4	100·0	99·7	84·0
April 3 " " 260....	98·2	93·6	99·9	96·1	100·0	98·2	100·0	99·5	98·8	100·1	99·2	101·4	99·9	84·2
June 12 " " 330....	99·1	95·4	100·0	98·5	100·8	99·3	100·4	100·1	99·4	100·8	99·7	101·8	100·9	86·1
August 9 " " 388....	99·0	96·2	100·3	99·2	101·0	99·5	100·6	100·5	100·1	101·5	99·9	101·8	101·4	89·3
November 19 " " 490....	98·7	94·4	100·3	96·9	100·8	98·5	100·4	100·1	98·9	101·1	99·7	101·8	100·4	84·9
December 26, 1911 " " 892....	100·3	94·7	100·8	97·3	101·0	98·5	100·4	100·6	99·2	102·3	100·1	102·3	101·5	85·5

TABLE XVII

WEATHERING TESTS OF COAL

1. Source of coal: SAMPLES OF COAL FROM THE INTERNATIONAL COAL & COKE CO., COLEMAN, ALTA., No. 4 SEAM, DENISON COLLIERY

2. Description of samples:
- Regular samples, run of mine coal (10-v-08)
- Extra sample for coking tests (27-vii-09)
- Sample Ex. 19 for weathering tests. Fresh coal taken from workings, 3 feet above floor of seam. (7-v-08)
- Sample Ex. 20 for weathering tests. Old coal from side of prospect tunnel, 40 feet from mouth and 250 feet from Ex. 19, 3 feet above floor of seam. Coal had been exposed for five years. (7-v-08)
- Sample Ex. 21 for weathering tests. Outcrop coal taken from under grass roots, about 100 feet from Ex. 20, 3 feet above floor of seam. (7-v-08)

	Regular sample	Mine moisture sample	Extra sample (coking)	Ex. 19 Raw coal in tubes (vii-08)	Ex. 19 Dry coal in tubes (vii-08)	Ex. 19 Raw coal in tubes (3-iv-09)	Ex. 19 Raw coal in tubes (12-vi-09)	Ex. 20 Raw coal in tubes (vii-08)	Ex. 20 Dry coal in tubes (vii-08)	Ex. 20 Raw coal in tubes (3-iv-09)	Ex. 20 Raw coal in tubes (12-vi-09)	Ex. 21 Raw coal in tubes (vii-08)	Ex. 21 Dry coal in tubes (vii-08)	Ex. 21 Raw coal in tubes (3-iv-09)	Ex. 21 Raw coal in tubes (12-vi-09)
3. Sample number	34 SP.	134 SP.	2034 SP.	Ex. 19 (raw)	Ex. 19 (dry)	Ex. 19 (special)	Ex. 19 (special)	Ex. 20 (raw)	Ex. 20 (dry)	Ex. 20 (special)	Ex. 20 (special)	Ex. 21 (raw)	Ex. 21 (dry)	Ex. 21 (special)	Ex. 21 (special)
Moisture in coal															
4. Total moisture %	1·1 (21-xii-08)	2·0 (vi-08)	2·4 (13-viii-09)	1·4 (29-x-08)		0·3	0·7 (19-vi-09)	1·5 (29-x-08)		0·3	0·8 (19-vi-09)	3·0 (29-x-08)		1·5	2·1 (19-vi-09)
5. Moisture in air dry coal %		0·6 (29-vi-08)													
Proximate analysis of coal															
6. Fixed carbon in dry coal—from analysis of raw coal (R) %	59·6			65·9			65·9				64·4				60·9
7. " " " " —from analysis of dry coal (D) %	60·0		58·4		65·8				64·7				60·6		
8. " " in dry and ash free coal—from R %	71·1			74·7			74·7				72·5				71·3
9. " " " " " —from D %	71·6		71·8		74·7				72·8				71·0		
10. Volatile matter in dry coal—from analysis of raw coal (R) %	24·2 (29-i-09)			22·1 (29-x-08)			22·3 (12-vi-09)	24·1 (29-x-08)			24·5 (12-vi-09)	24·9 (29-x-08)			24·5 (12-vi-09)
11. " " " " " —from analysis of dry coal (D) %	23·8 (25-viii-08)		22·9 (16-viii-09)		22·5 (11-vi-09)				24·3 (11-vi-09)				24·5 (11-vi-09)		
12. " " in dry and ash free coal—from R %	28·9			25·3							27·5				28·7
13. " " " " " —from D %	28·4		28·2		25·3				27·2				29·0		
14. Ash in dry coal—coal burnt in muffle %	16·2 (2-vii-08)	18·2 (30-vi-08)	18·7 (14-viii-09)	11·9 (29-x-08)	11·9		11·8 (21-vi-09)	11·1 (29-x-08)	11·1		11·1 (21-vi-09)	14·7 (29-x-08)	14·7		14·6 (21-vi-09)
15. Fuel ratio FC/VM—from R	2·46						2·96				2·63				2·48
16. " " —from D	2·52		2·55		2·95				2·68				2·45		
Ultimate analysis of coal															
17. Carbon in dry coal—from analysis of raw coal (R) %				78·4 (ii-09)		77·6 (iv-09)		78·0 (iii-09)		78·7 (iv-09)		71·4 (iii-09)		70·2 (iv-09)	
18. " " " " —from analysis of dry coal (D) %	72·6 (16-i-09)				77·5 (ii-09)				77·6 (iii-09)				70·4 (iii-09)		
19. " " in dry and ash free coal—from R %				89·0		88·0		88·0		88·7		83·8		82·4	
20. " " " " " —from D %	86·8				87·9				87·5				82·5		
21. Hydrogen in dry coal—from analysis of raw coal (R) %				3·96 (ii-09)		4·18 (iv-09)		4·23 (iii-09)		4·14 (iv-09)		3·48 (iii-09)		3·72 (iv-09)	
22. " " " " —from analysis of dry coal (D) %	4·27 (16-i-09)				3·99 (ii-09)				4·37 (iii-09)				3·68 (iii-09)		
23. " " in dry and ash free coal—from R %				4·50		4·75		4·76		4·67		4·09		4·36	
24. " " " " " —from D %	5·10				4·52				4·92				4·32		
25. Sulphur in dry coal %	0·6 (29-vi-08)		0·6 (16-viii-09)	0·5	0·5 (23-vi-09)	0·5		0·6	0·6 (21-vi-09)	0·6		0·4	0·4 (22-vi-09)	0·4	
26. " dry and ash free coal %	0·7			0·6	0·6	0·6		0·7	0·7	0·7		0·5	0·5	0·5	
27. Nitrogen in dry coal %	1·0 (7-v-08)			1·0	1·0 (4-vi-09)	1·0		1·1	1·1 (4-vi-09)	1·1		0·9	0·9 (5-vi-09)	0·9	
28. " in dry and ash free coal %	1·2			1·1	1·1	1·1		1·2	1·2	1·2		1·0	1·0	1·0	
29. Oxygen in dry coal—from analysis of raw coal (R) %				4·1		4·7		4·7		4·2		9·0		10·0	
30. " " " —from analysis of dry coal (D) %	5·2				5·2				5·1				9·9		
31. " in dry and ash free coal—from R %				4·8		5·5		5·3		4·7		10·6		11·7	
32. " " " " " —from D %	6·2				5·9				5·7				11·7		
33. Ash in dry coal—coal burned in oxygen %	16·3 (16-i-09)			12·0 (ii-09)	11·8 (i-09)	12·0 (iv-09)		11·4 (iii-09)	11·2 (iii-09)	11·3 (iv-09)		14·8 (iii-09)	14·7 (iii-09)	14·8 (iv-09)	
34. Carbon-hydrogen ratio, C/H—from R				19·8		18·6		18·4		19·0		20·5		18·9	
35. " " " —from D	17·0				19·4				17·8				19·1		
Calorific value of coal															
36. On dry and ash free coal—from determination (calories)	8310 (11-v-09)		8280 (10-xi-09)												
37. " " " " " —from ultimate analysis (calories)	8520			8550	8420	8530		8540	8540	8590		7740	7670	7670	
38. Colour of ground coal						Black				Black				Black	
39. Coking properties					Fair coke		Barely coked		Fair coke	Fair coke			Non-coking		Non-coking

TABLE XIV

WEATHERING TESTS OF COAL

1. Source of coal — SAMPLES OF COAL FROM THE DOMINION COAL CO., DOMINION No. 12, LINGAN, C.B.

2. Description of samples	Regular samples, coal taken from dump, mined a few hours before, run of mine coal (27-vi-08)		Extra sample for coking tests. (20-vi-09)	Sample Ex. 27 for weathering tests taken one-third distance from roof, in main slope, 125 feet away from Ex. 28. Exposed for three or four months. (27-vi-08)				Sample Ex. 28, outcrop coal for weathering tests, taken from main slope at point of natural outcrop, from untimbered entrance, and from same bench in seam as sample Ex. 27. (27-vi-08)			
						Exposed on tray (17-vii-08)				Exposed on tray (17-vii-08)	
	Regular sample	Mine moisture sample		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Raw coal put in tubes. (3-iv-09)	Raw coal put in tubes. (12-vi-09)	Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Raw coal put in tubes. (3-iv-09)	Raw coal put in tubes. (12-vi-09)
3. Sample number	39	139	2039	Ex. 27 (raw)	Ex. 27 (dry)	Ex. 27 (special)	Ex. 27 (special)	Ex. 28 (raw)	Ex. 28 (dry)	Ex. 28 (special)	Ex. 28 (special)
Moisture in coal											
4. Total moisture..........%	4·1 (21-xii-08)	4·9 (vii-08)	....	4·2 (2-xi-08)	....	1·4	2·3 (21-vi-09)	10·1 (2-xi-08)	....	4·0	6·1 (21-vi-09)
5. Moisture in air dry coal..........%		3·6 (30-vii-08)	....	....							
Proximate analysis of coal											
6. Fixed carbon in dry coal—from analysis of raw coal (R)....%	57·2	....				58·8					57·1
7. " " " " —from analysis of dry coal (D).....%	58·0		58·8		53·0				56·8		
8. " " in dry and ash free coal—from R..........%	60·1					60·0					60·1
9. " " " " " —from D..........%	60·9		61·3		59·1				59·8		
10. Volatile matter in dry coal—from analysis of raw coal (R)..%	38·0 (1-ii-09)					39·3 (12-vi-09)					38·0 (12-vi-09)
11. " " " " " —from analysis of dry coal (D)...%	37·2 (12-viii-08)		37·1 (26-iii-09)		40·0 (30-x-08) 40·0 (11-vi-09)				37·8 (30-x-08) 38·6 (11-vi-09)		
12. " " in dry and ash free coal—from R..........%	39·9					40·0					39·9
13. " " " " " " " —from D..........%	39·1		38·7		40·9				40·2		
14. Ash in dry coal—coal burnt in muffle..........%	4·8 (29-vii-08)	6·3 (31-vii-08)	4·1 (1-iv-09)	2·0 (2-xi-08)	2·0	....	1·9 (22-vi-09)	5·0 (2-xi-08)	5·0	....	4·9 (22-vi-09)
15. Fuel ratio FC/VM—from R..........%	1·51					1·50					1·50
16. " " " —from D..........%	1·56		1·58		1·45				1·49		
Ultimate analysis of coal											
17. Carbon in dry coal—from analysis of raw coal (R)..........%				82·5 (2-iii-09)		80·0 (3-iv-09)		74·2 (iii-09)		69·2 (3-iv-09)	
18. " " " " —from analysis of dry coal (D)..........%	77·7 (6-ii-09)		80·4 (2-iii-09)		81·0 (iii-09)				71·9 (iii-09)		
19. " in dry and ash free coal—from R..........%				84·3		81·8		78·1		72·7	
20. " " " " " " —from D..........%	82·1		84·3		82·7				75·5		
21. Hydrogen in dry coal—from analysis of raw coal (R)..........%				5·33 (2-iii-09)		5·46 (3-iv-09)		4·13 (iii-09)		4·45 (3-iv-09)	
22. " " " " —from analysis of dry coal (D)..........%	5·18 (6-ii-09)		5·48 (2-iii-09)		5·54 (iii-09)				4·49 (iii-09)		
23. " in dry and ash free coal—from R..........%				5·44		5·58		4·35		4·67	
24. " " " " " " —from D..........%	5·48		5·74		5·65				4·72		
25. Sulphur in dry coal..........%	1·8 (11-viii-08)		1·6 (13-vii-09)	1·1	1·1 (23-vi-09)	1·1		0·6	0·6 (22-vi-09)	0·6	
26. " " dry and ash free coal..........%	1·9		1·7	1·1	1·1	1·1		0·6	0·6	0·6	
27. Nitrogen in dry coal..........%	1·6 (10-v-08)		1·6 (2-vi-09)	1·7	1·7 (7-vi-09)	1·7		1·5	1·5 (7-vi-09)	1·5	
28. " in dry and ash free coal..........%	1·7		1·7	1·7	1·7	1·7		1·6	1·6	1·6	
29. Oxygen in dry coal—from analysis of raw coal (R)..........%				7·3		9·5		14·6		19·4	
30. " " " —from analysis of dry coal (D)..........%	8·3		6·3		8·7				16·7		
31. " in dry and ash free coal—from R..........%				7·5		9·8		15·3		20·4	
32. " " " " " —from D..........%	8·8		6·6		8·8				17·6		
33. Ash in dry coal—coal burned in oxygen..........%	5·4 (6-ii-09)		4·6 (2-iii-09)	2·1	2·0 (iii-09)	2·2		5·0 (iii-09)	4·8 (iii-09)	4·8 (3-iv-09)	
34. Carbon-hydrogen ratio, C/H—from R..........%				15·5		14·6		18·0		15·5	
35. " " " —from D..........%	15·0		14·7		14·6				16·0		
Calorific value of coal											
36. On dry and ash free coal—from determination........calories	8050 (11-v-09)										
37. " " " " " —from ultimate analysis......calories	8185		8540	8390	8270	8140		7170	6980	6620	
38. Colour of ground coal					Black with brown tinge				Black		
39. Coking properties					Fairly good but friable coke		Fairly good coke		Non-coking		Non-coking

TABLE XV
WEATHERING TESTS OF COAL

1. Source of coal .... SAMPLES OF COAL FROM THE WEST CANADIAN COLLIERIES CO., BELLEVUE COLLIERY, ALTA., SEAMS 1 and 2.

2. Description of samples:
- Regular samples, run of mine coal, No. 1 seam (5-v-08)
- Extra sample for coking tests, No. 1 seam (29-vii-09)
- Sample Ex. 16 for weathering tests, from No. 2 seam. Taken from near face of tunnel after removing 6″ to 8″ of coal—surface had been exposed between six and twelve months (5-v-08). Exposed on tray (17-vii-08).
- Sample Ex. 15 for weathering tests, outcrop coal from No. 2 seam. Outcrop exposed by trench at the lower end of which is a short tunnel (in which Ex. 16 was taken). Outcrop before being revealed by trench was covered by drift to a depth of several feet (5-v-08). Exposed on tray (17-vii-08).

	Regular sample (No. 1 seam)	Mine moisture sample	Extra coking tests (No. 1 seam)	Ex. 16 Raw coal put in tubes (vii-08)	Ex. 16 Dry coal put in tubes (vii-08)	Ex. 16 special Raw coal in tubes (3-iv-09)	Ex. 16 special Raw coal in tubes (11-vi-09)	Ex. 15 Raw coal put in tubes (vii-08)	Ex. 15 Dry coal put in tubes (vii-08)	Ex. 15 special Raw coal in tubes (3-iv-09)	Ex. 15 special Raw coal in tubes (11-vi-09)
3. Sample number	33	133	2033	Ex. 16 (raw)	Ex. 16 (dry)	Ex. 16 (special)	Ex. 16 (special)	Ex. 15 (raw)	Ex. 15 (dry)	Ex. 15 (special)	Ex. 15 (special)
Moisture in coal											
4. Total moisture %	1·0 (2-xi-08)	0·9 (v-08)		1·3 (2-xi-08)		0·8	0·9 (19-vi-09)	12·9 (2-xi-08)		5·9	8·2 (19-vi-09)
5. Moisture in air dry coal %		0·2 (11-vi-08)									
Proximate analysis of coal											
6. Fixed carbon in dry coal—from analysis of raw coal (R) %	56·8					55·0				49·2	
7. " —from analysis of dry coal (D) %	56·9		59·2		54·4				48·6		
8. " in dry and ash free coal—from R %	67·2					65·9				58·2	
9. " —from D %	67·3		68·8		65·2				57·6		
10. Volatile matter in dry coal—from analysis of raw coal (R) %	27·7 (29-i-09)					28·4 (12-vi-09)				35·4 (12-vi-09)	
11. " —from analysis of dry coal (D) %	27·6 (25-vi-08)		26·7 (16-viii-09)		28·9 (30-x-08) 29·2 (11-vi-09)				35·9 (30-x-08) 35·7 (11-vi-09)		
12. " in dry and ash free coal—from R %	32·8					34·1				41·8	
13. " —from D %	32·7		31·2		34·8				42·4		
14. Ash in dry coal—coal burnt in muffle %	15·5 (24-vi-08)	12·9 (13-vi-08)	14·1 (14-viii-09)	16·6 (2-xi-08)	16·6		16·6 (21-vi-09)	15·6 (29-x-08)	15·6		15·4 (21-vi-09)
15. Fuel ratio FC/VM—from R	2·05					1·94				1·39	
16. " —from D	2·06		2·22		1·87				1·36		
Ultimate analysis of coal											
17. Carbon in dry coal—from analysis of raw coal (R) %				71·5 (25-ii-09)		70·0 (3-iv-09)		63·8 (24-ii-09)		62·8 (2-iv-09)	
18. " —from analysis of dry coal (D) %	71·5 (11-i-09)				70·0 (24-ii-09)				60·5 (23-ii-09)		
19. " in dry and ash free coal—from R %				85·8		84·0		75·6		74·5	
20. " —from D %	84·8				84·0				71·1		
21. Hydrogen in dry coal—from analysis of raw coal (R) %				4·31 (25-ii-09)		4·41 (3-iv-09)		2·74 (24-ii-09)		3·30 (2-iv-09)	
22. " —from analysis of dry coal (D) %	4·34 (11-i-09)				4·53 (24-ii-09)				3·67 (23-ii-09)		
23. " in dry and ash free coal—from R %				5·17		5·28		3·25		3·91	
24. " —from D %	5·15				5·43				4·32		
25. Sulphur in dry coal %	0·8 (29-vi-08)		0·9 (16-viii-09)	1·0	1·0 (21-vi-09)	1·0		0·4	0·4 (21-vi-09)	0·4	
26. " in dry and ash free coal %	0·9			1·2	1·2	1·2		0·5	0·5	0·5	
27. Nitrogen in dry coal %	1·1 (7-v-08)			1·0	1·0 (4-vi-09)	1·0		0·9	0·9 (4-vi-09)	0·9	
28. " in dry and ash free coal %	1·2			1·2	1·2	1·2		1·1	1·1	1·1	
29. Oxygen in dry coal—from analysis of raw coal (R) %				5·5		7·0		16·5		16·9	
30. " —from analysis of dry coal (D) %	6·6				6·9				19·5		
31. " in dry and ash free coal—from R %				6·6		8·3		19·5		20·0	
32. " —from D %	7·9				8·2				23·0		
33. Ash in dry coal—coal burned in oxygen %	15·7 (11-i-09)			16·7 (25-ii-09)	16·6 (24-ii-09)	16·6 (3-iv-09)		15·7 (24-ii-09)	15·0 (23-ii-09)	15·7 (2-iv-09)	
34. Carbon-hydrogen ratio, C/H—from R				16·6		15·9		23·3		19·0	
35. " —from D	16·5				15·5				16·5		
Calorific value of coal											
36. On dry and ash free coal—from determination ... calories	8140 (14-iv-09)		8150 (5-xi-09)	8460	8330	8270		6400	6260	6520	
37. " —from ultimate analysis ... calories	8300										
38. Colour of ground coal						Black brown				Slightly brown black	
39. Coking properties					Medium coke		Medium coke			Non-coking	Non-coking

TABLE XVI

WEATHERING TESTS OF COAL

1. Source of coal — SAMPLES OF COAL FROM THE WEST CANADIAN COLLIERIES CO., LILLE COLLIERY, ALTA., No. 1 SEAM

2. Description of samples — Regular samples, run of mine coal (6-v-08); Extra sample for coking tests (30-vii-09); Sample Ex. 18 for weathering tests. Coal taken from side of seam after removing 8″ of coal from surface at 24 feet from mouth of prospecting slope two years old (6-v-08); Sample Ex. 17 for weathering tests. Old coal from surface of side of seam at 3 feet from mouth of prospecting slope two years old. This sample does not represent outcrop weathering (6-v-08).

	Regular sample	Mine moisture sample	Extra sample for coking tests	Ex. 18 Raw coal put in tubes (vii-08)	Ex. 18 Dry coal put in tubes (vii-08)	Ex. 18 Exposed on tray — Raw coal put in tubes (3-iv-09)	Ex. 18 Exposed on tray — Raw coal put in tubes (12-vi-09)	Ex. 17 Raw coal put in tubes (vii-08)	Ex. 17 Dry coal put in tubes (vii-08)	Ex. 17 Exposed on tray — Raw coal put in tubes (3-iv-09)	Ex. 17 Exposed on tray — Raw coal put in tubes (12-vi-09)
3. Sample number	28	128	2028	Ex. 18 (raw)	Ex. 18 (dry)	Ex. 18 (special)	Ex. 18 (special)	Ex. 17 (raw)	Ex. 17 (dry)	Ex. 17 (special)	Ex. 17 (special)
Moisture in coal											
4. Total moisture %	0·9 (2-xi-08)	1·7 (v-08)	1·5 (12-viii-09)	1·2 (2-xi-08)		0·2	1·0 (19-vi-09)	4·6 (2-xi-08)		2·2	3·2 (19-vi-09)
5. Moisture in air dry coal %		0·8 (11-vi-08)									
Proximate analysis of coal											
6. Fixed carbon in dry coal—from analysis of raw coal (R) %	58·8					63·5				63·4	
7. " " " " "—from analysis of dry coal (D) %	58·5		58·9		62·4				61·7		
8. " " in dry and ash free coal—from R %	70·3					68·5				71·2	
9. " " " " " " "—from D %	70·0		70·0		67·5				69·5		
10. Volatile matter in dry coal—from analysis of raw coal (R) %	24·8 (28-i-09)						29·2 (12-vi-09)				25·6 (12-vi-09)
11. " " " " "—from analysis of dry coal (D) %	25·1 (25-vi-08)		25·3 (13-viii-09)		30·4 (30-x-08)				28·1 (30-x-08)		
12. " " in dry and ash free coal—from R %	29·7				29·9 (11-vi-09)		31·5		26·2 (11-vi-09)		
13. " " " " " " "—from D %	30·0		30·0		32·5				30·5		
14. Ash in dry coal—coal burnt in muffle %	16·4 (24-vi-08)	16·0 (13-vi-08)	15·8 (13-viii-09)	7·5 (29-x-08)	7·5		7·3 (21-vi-09)	11·2 (29-x-08)	11·2		11·0 (21-vi-09)
15. Fuel ratio FC/VM—from R	2·37					2·18					
16. " " "—from D	2·33		2·32		2·07						
Ultimate analysis of coal											
17. Carbon in dry coal—from analysis of raw coal (R) %				80·5 (ii-09)		79·7 (3-iv-09)		72·5 (ii-09)		71·5 (3-iv-09)	
18. " " " " "—from analysis of dry coal (D) %	71·2 (4-i-09)				80·1 (ii-09)				71·6 (25-ii-09)		
19. " in dry and ash free coal—from R %				86·8		86·1		81·8		80·6	
20. " " " " " "—from D %	85·2				86·6				80·6		
21. Hydrogen in dry coal—from analysis of raw coal (R) %				4·61 (ii-09)		4·86 (3-iv-09)		3·53 (ii-09)		3·82 (3-iv-09)	
22. " " " "—from analysis of dry coal (D) %	4·25 (4-i-09)				4·84 (ii-09)				3·89 (25-ii-09)		
23. " in dry and ash free coal—from R %				4·97		5·25		3·99		4·30	
24. " " " " " "—from D %	5·09				5·24				4·38		
25. Sulphur in dry coal %	0·5 (29-vi-08)		0·6 (14-viii-09)	0·8	0·8 (21-vi-09)	0·8		0·5	0·5 (21-vi-09)	0·5	
26. " in dry and ash free coal %	0·6			0·9	0·9	0·9		0·6	0·6	0·6	
27. Nitrogen in dry coal %	0·9 (6-v-08)			1·1	1·1 (4-vi-09)	1·1		0·8	0·8 (4-vi-09)	0·8	
28. " in dry and ash free coal %	1·1			1·2	1·2	1·2		0·9	0·9	0·9	
29. Oxygen in dry coal—from analysis of raw coal (R) %				5·7		6·0		11·4		12·2	
30. " " " "—from analysis of dry coal (D) %	6·7				5·7				12·1		
31. " in dry and ash free coal—from R %				6·1		6·5		12·7		13·6	
32. " " " " " "—from D %	8·0				6·1				13·5		
33. Ash in dry coal—coal burned in oxygen %	16·4 (4-i-09)			7·3 (ii-09)	7·5 (ii-09)	7·5 (3-iv-09)		11·3 (ii-09)	11·1 (25-ii-09)	11·2 (3-iv-09)	
34. Carbon-hydrogen ratio, C/H—from R				17·5		16·4		20·5		18·7	
35. " " " " "—from D	16·8				16·5				18·4		
Calorific value of coal											
36. On dry and ash free coal—from determination ...calories	8290 (10-v-09)			8490	8570	8510		7450	7450	7420	
37. " " " " "—from ultimate analysis ...calories	8300		8330 (27-x-09)								
38. Colour of ground coal						Brownish black				Black	
39. Coking properties					Medium hard coke	Hard coke			Non-coking	Non-coking	

TABLE XVIII

WEATHERING TESTS OF COAL

1. Source of coal .... SAMPLES OF COAL FROM THE CROWSNEST PASS COAL CO., No. 3 MINE, MICHEL COLLIERY, B.C.

2. Description of samples:
   - Regular samples, coal over 2″ screen and picking belt. (30-iv-08)
   - Extra sample for coking tests. (27-vii-09)
   - Sample Ex. 23 for weathering tests. Taken in old tipple tunnel, 30 feet from mouth, after removing 10″ to 12″ of the surface coal. Surface had been exposed 8¾ years. (7-v-08)
   - Sample Ex. 22 for weathering tests. Coal exposed 8¾ years. Taken in old tipple tunnel 30 feet from mouth by scraping exposed surface with fingers (7-v-08)

	Regular sample	Mine moisture sample	Extra coking	Ex. 23 raw put in tubes (vii-08)	Ex. 23 dry put in tubes (vii-08)	Ex. 23 special, exposed on tray (17-vii-08), raw coal put in tubes (3-iv-09)	Ex. 23 special, exposed on tray (17-vii-08), raw coal put in tubes (12-vi-09)	Ex. 22 raw coal put in tubes (vii-08)	Ex. 22 dry coal put in tubes (vii-08)	Ex. 22 special, exposed on tray (17-vii-08), raw coal put in tubes (3-iv-09)	Ex. 22 special, exposed on tray (17-vii-08), raw coal put in tubes (12-vi-09)
3. Sample number	31	131	2031	Ex. 23 (raw)	Ex. 23 (dry)	Ex. 23 (special)	Ex. 23 (special)	Ex.22 (raw)	Ex. 22 (dry)	Ex. 22 (special)	Ex. 22 (special)
Moisture in coal											
4. Total moisture ....%	0·7 (2-xi-08)	1·4 (v-08)	1·0 (13-viii-09)	1·0 (29-x-08)	....	0·1	0·7 (21-vi-09)	1·4 (29-x-08)	....	0·0	0·5 (21-vi-09)
5. Moisture in air dry coal ....%		0·4 (11-vi-08)									
Proximate analysis of coal											
6. Fixed carbon in dry coal—from analysis of raw coal (R) ....%	62·4						71·4				55·2
7. " " " " —from analysis of dry coal (D) ....%	62·8		66·6		71·6				55·0		
8. " " in dry and ash free coal—from R ....%	71·3						73·8				71·0
9. " " " " " " " " —from D ....%	71·8		75·6		74·0				70·7		
10. Volatile matter in dry coal—from analysis of raw coal (R) ....%	25·1 (28-i-09)						25·3 (12-vi-09)				22·6 (12-vi-09)
11. " " " " —from analysis of dry coal (D) ....%	24·7 (10-vi-08)		21·5 (13-viii-09)		25·0 (30-x-08) 25·2 (11-vi-09)				23·1 (30-x-08) 22·6 (11-vi-09)		
12. " " in dry and ash free coal—from R ....%	28·7						26·2				29·0
13. " " " " " " " " —from D ....%	28·2		24·4		26·0				29·3		
14. Ash in dry coal—coal burnt in muffle ....%	12·5 (17-vi-08)	10·0 (13-vi-08)	11·9 (14-viii-09)	3·3 (29-x-08)	3·3		3·3 (22-vi-09)	22·2 (29-x-08)	22·2		
15. Fuel ratio FC/VM—from R	2·49						2·82				2·44
16. " " " —from D	2·54		3·10		2·85				2·41		
Ultimate analysis of coal											
17. Carbon in dry coal—from analysis of raw coal (R) ....%				86·1 (iii-09)		84·8 (3-iv-09)		67·7 (iii-09)		67·1 (iv-09)	
18. " " —from analysis of dry coal (D) ....%	75·5 (9-i-09)				85·3 (iii-09)				66·8 (iii-09)		
19. " in dry and ash free coal—from R ....%				89·1		87·7		87·5		86·0	
20. " " " " " " " " —from D ....%	86·4				88·3				86·2		
21. Hydrogen in dry coal—from analysis of raw coal (R) ....%				4·89 (iii-09)		4·99 (3-iv-09)		4·24 (iii-09)		4·20 (iv-09)	
22. " " —from analysis of dry coal (D) ....%	4·3 (9-i-09)				5·02 (iii-09)				4·39 (iii-09)		
23. " in dry and ash free coal—from R ....%				5·06		5·16		5·48		5·38	
24. " " " " " " " " —from D ....%	4·9				5·19				5·66		
25. Sulphur in dry coal ....%	0·5 (15-vi-08)		0·5 (16-viii-09)	0·4	0·4 (22-vi-09)	0·4		0·5	0·5 (22-vi-09)	0·5	
26. " " dry and ash free coal ....%	0·6			0·4	0·4	0·4		0·6	0·6	0·6	
27. Nitrogen in dry coal ....%	1·2 (6-v-08)			1·5	1·5 (5-vi-09)	1·5		1·2	1·2 (5-vi-09)	1·2	
28. " " in dry and ash free coal ....%	1·4			1·5	1·5	1·5		1·5	1·5	1·5	
29. Oxygen in dry coal—from analysis of raw coal (R) ....%				3·7		5·0		3·8		5·0	
30. " " " " —from analysis of dry coal (D) ....%	5·9				4·5				4·6		
31. " in dry and ash free coal—from R ....%				3·9		5·2		4·9		6·5	
32. " " " " " " " " —from D ....%	6·7				4·6				6·0		
33. Ash in dry coal—coal burned in oxygen ....%	12·6 (9-i-09)			3·4 (iii-09)	3·3 (iii-09)	3·3 (3-iv-09)		22·6 (iii-09)	22·5 (iii-09)	22·0 (iv-09)	
34. Carbon-hydrogen ratio, C/H—from R				17·6		17·40		16·0		16·0	
35. " " " " —from D	17·5				17·0				15·2		
Calorific value of coal											
36. On dry and ash free coal—from determination ....calories	8420 (27-iv-09)		8520 (16-xi-09)								
37. " " " " " —from ultimate analysis ....calories	8370			8780	8730	8640		8760	8660	8540	
38. Colour of ground coal					Black				Rather brown		
39. Coking properties	Cokes				Cokes		Cokes		Hard coke		Cokes fairly well

TABLE XIX

WEATHERING TESTS OF COAL

1. Source of coal. SAMPLES OF COAL FROM THE NICOLA VALLEY COAL & COKE CO., No. 2 MINE, MIDDLESBORO COLLIERY, B.C.

2. Description of samples.

- Regular samples, coal taken from bank, freshly mined run of mine coal. (18-iv-08)
- Sample Ex. 25, for weathering tests; fresh coal taken 1400 feet from portal. (2-vi-08)
- Sample Ex. 26, for weathering tests, weathered coal taken 80 feet from portal, where it had been exposed for 10½ months. (2-vi-08)
- Sample Ex. 24, for weathering tests, outcrop coal taken from under 3 feet of surface drift. (2-vi-08)

	Regular sample	Mine moisture sample	Ex. 25 raw coal in tubes (vii-08)	Ex. 25 dry coal in tubes (vii-08)	Ex. 25 raw in tubes (3-iv-09)	Ex. 25 raw in tubes (12-vi-09)	Ex. 26 raw coal in tubes (vii-08)	Ex. 26 dried coal in tubes (vii-08)	Ex. 26 raw in tubes (3-iv-09)	Ex. 26 raw in tubes (12-vi-09)	Ex. 24 raw coal in tubes (vii-08)	Ex. 24 dried coal in tubes (vii-08)	Ex. 24 raw in tubes (3-iv-09)	Ex. 24 raw in tubes (12-vi-09)
3. Sample number	22 SP.	122 SP.	Ex. 25 (raw)	Ex. 25 (dry)	Ex. 25 (special)	Ex. 25 (special)	Ex. 26 (raw)	Ex. 26 (dry)	Ex. 26 (special)	Ex. 26 (special)	Ex. 24 (raw)	Ex. 24 (dry)	Ex. 24 (special)	Ex. 24 (special)
Moisture in coal														
4. Total moisture %	2·7 (18-iv-08)	2·9 (vii-08)	2·6 (29-x-08)	....	1·3	1·7 (21-vi-09)	4·1 (2-xi-08)	....	1·2	2·1 (21-vi-09)	25·5 (29-x-08)	....	7·4	9·5 (21-vi-09)
5. Moisture in air dry coal %		2·3 (30-vii-08)												
Proximate analysis of coal														
6. Fixed carbon in dry coal—from analysis of raw coal (R) %	47·3					54·8				53·7				45·9
7. " " " —from analysis of dry coal (D) %	48·1			54·5				52·5				47·8		
8. " " in dry and ash free coal—from R %	54·3					57·1				56·0				50·2
9. " " " " " " " —from D %	55·2			56·7				54·6				52·3		
10. Volatile matter in dry coal—from analysis of raw coal (R) %	39·8 (28-i-09)					41·1 (12-vi-09)				42·4 (12-vi-09)				45·4 (12-vi-09)
11. " " " —from analysis of dry coal (D) %	39·0 (25-vi-08)			40·8 (30-x-08) 42·4 (11-vi-09)				44·0 30-x-08) 43·2 (11-vi-09)				43·2 (30-x-08) 43·9 (11-vi-09)		
12. " " in dry and ash free coal—from R %	45·7					42·9				44·0				49·8
13. " " " " " " " —from D %	44·8			43·3				45·4				47·7		
14. Ash in dry coal—coal burnt in muffle %	12·9 (19-vi-08)	11·4 (30-vii-08)	3·9 (29-x-08)	3·9		4·1 (22-vi-09)	3·9 (29-x-08)	3·9		3·9 (22-vi-09)	8·6 (29-x-09)	8·6		8·7 (22-vi-09)
15. Fuel ratio FC/VM—from R	1·19					1·33				1·27				1·01
16. " " —from D	1·23			1·31				1·20				1·10		
Ultimate analysis of coal														
17. Carbon in dry coal—from analysis of raw coal (R) %			79·0 (iii-09)		78·1 (iv-09)		78·8 (iii-09)		77·3 (iv-09)		64·5 (iii-09)		61·9 (iv-09)	
18. " " —from analysis of dry coal (D) %	69·4 (9-ii-09)			78·2 (iii-09)				76·6 (iii-09)				60·7 (iii-09)		
19. " in dry and ash free coal—from R %			82·4		81·6		82·2		80·5		70·5		67·5	
20. " " " " " " " —from D %	79·9			81·7				79·7				66·0		
21. Hydrogen in dry coal—from analysis of raw coal (R) %			5·70 (iii-09)		5·61		5·55 (iii-09)		5·74 (iv-09)		3·02 (iii-09)		3·82 (iv-09)	
22. " " " —from analysis of dry coal (D) %	5·11 (9-ii-09)			5·87 (iii-09)				5·85 (iii-09)				4·07 (iii-09)		
23. " in dry and ash free coal—from R %			5·94		5·86 (iv-09)		5·79		5·98		3·30		4·13	
24. " " " " " —from D %	5·88			6·13				6·09				4·42		
25. Sulphur in dry coal %	0·7 (15-vi-08)		0·5	0·5 (22-vi-09)	0·5		0·5	0·5 (22-vi-09)	0·5		0·4	0·4 (22-vi-09)	0·4	
26. " " dry and ash free coal %	0·8		0·5	0·5	0·5		0·5	0·5	0·5		0·4	0·4	0·4	
27. Nitrogen in dry coal %	2·0 (5-v-08)		2·3	2·3 (7-vi-09)	2·3		2·2	2·2 (7-vi-09)	2·2		2·0	2·0 (5-vi-09)	2·0	
28. " in dry and ash free coal %	2·3		2·4	2·4	2·4		2·3	2·3	2·3		2·2	2·2	2·2	
29. Oxygen in dry coal—from analysis of raw coal (R) %			8·4		9·2		8·8		10·3		21·5		23·6	
30. " " —from analysis of dry coal (D) %	9·7			8·8				10·9				24·9		
31. " in dry and ash free coal—from R %			8·8		9·6		9·2		10·7		23·6		25·8	
32. " " " " " " " —from D %	11·1			9·3				11·4				27·0		
33. Ash in dry coal—coal burned in oxygen %	13·1 (9-ii-09)		4·1 (iii-09)	4·3 (iii-09)	4·3 (iv-09)		4·1 (iii-09)	3·9 (iii-09)	4·0 (iv-09)		8·6 (iii-09)	7·9 (iii-09)	8·3 (iv-09)	
34. Carbon-hydrogen ratio, C/H—from R			13·9		13·9		14·2		13·5		21·4		16·2	
35. " " —from D	13·6			13·3				13·1				14·9		
Calorific value of coal														
36. On dry and ash free coal—from determination calories	7760 (21-iv-09)		8340	8320	8210		8250	8060	8110		5820	5700	5780	
37. " " " " " —from ultimate analysis calories	8030													
38. Colour of ground coal					Black with brown tinge				Black			Very brown		
39. Coking properties				Medium coke		Medium coke			Medium coke	Poor coke		Non-coking		Non-coking

SPONTANEOUS COMBUSTION OF COAL

(Being a paper read before the Canadian Mining Institute, March, 1910, by Edgar Stansfield, M.Sc., McGill University, Montreal.)

Introductory Note.

The writer of the following paper had hoped that when the regular work of the coal tests was completed he would be able to carry out an investigation on the spontaneous combustion of coal. As a preparation for this work he made a study of the literature of the subject, and wrote the following summary for presentation to the Annual Meeting of the Canadian Mining Institute, held at Toronto, March 1910. He was, however, unable to take part in this investigation himself, but Dr. J. B. Porter, with other assistants, has carried on an investigation during the past two years, and it is hoped to publish their results, together with a further historical introduction, within a few months, as Vol. VII of this report.

The paper is reprinted, by permission, from Volume XIII of the proceedings of the Canadian Mining Institute. Some small changes have been made; but no attempt has been made to bring it up to date. For further and later information Volume VII should be consulted.

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The deterioration of stored coal is a very serious matter to all large dealers and consumers, and fuller and more definite information on the subject is urgently needed. A study of the extensive literature bearing upon spontaneous combustion has shown that although much has been accomplished, a great deal more remains to be done. This literature[1] is not easily accessible and although there have been excellent summaries published, these chiefly refer to the question of the shipment of coal cargoes, so that there does seem a need for a statement as to the known facts and present theories with especial reference to land storage. It is this need that the present paper is an attempt to fulfil.

Spontaneous combustion of coal may be considered under three classes: fires in the mines, fires in ships, and fires in land storage. All these may at times be of very grave importance; they have all three caused the loss of incalculable sums of money and the first two have resulted in the loss of very many lives.

A few examples will illustrate the importance of the subject:—

At the Hamstead colliery in South Staffordshire, England, is worked what is known as the "Thick Coal Seam," there about 20 feet thick. This seam is not gassy, but is extremely liable to fire spontaneously. There were no less than 200 fires in the 20,000 feet of return airways in 1895, and 250 in 1896. In November 1898 a fire broke out so suddenly and acquired

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[1] The writer wishes to acknowledge his great indebtedness for aid in the writing of the paper, and for his diagrams to the Report of the New South Wales Royal Commission (1897), and to a paper by Prof. R. Threlfall "The Spontaneous Heating of Coal Particularly During Shipment" (J. Soc. Chem. Indust. July 31, 1909, pp. 759-773). The following papers have also been freely made use of: "The Spontaneous Ignition of Coal and its Prevention," by Prof. Vivian B. Lewes (J. Soc. of Arts, Vol. 40, 1892, pp. 352-365), and "The Spontaneous Combustion of Coal on Board Ship," by Commander W. F. Caborne, C.B., R.N.R., (J. Roy. United Services Inst., XLVI, p. 285, and reprinted in The Mining Journal LXXII, 1902, p. 124 *et seq.*).

such magnitude that the mine had to be closed, and this in spite of elaborate precautions and almost constant inspection.

In the nine years between 1873 and 1883, fifty-seven boats leaving British ports with coal cargoes are known to have been lost owing to spontaneous combustion. Three hundred and twenty-eight others disappeared during the same time, and we can only guess at their fate. These figures only refer to vessels actually lost. In 1874 alone, seventy cargoes either fired or heated.

During the last two or three years the writer has seen or heard of several spontaneous fires of both Cape Breton and Pennsylvanian coal stored in Montreal. The following is an extract from a letter received by Dr. Porter from the President of an Ontario firm using Pennsylvanian slack coal: "With reference to the trouble with our coal pile here, I am sorry to say that the conditions got very much worse after I wrote you on September 24, and I found that the greater part of the dump was beginning to heat. . . . The only lot of coal that we have that does not appear to be more or less hot is one comparatively small pile that stands by itself. . . . I must say our experience this year has discouraged me from trying to handle a large dump of slack coal, which is very unfortunate, as it is much the cheapest and most satisfactory way for us to handle our coal, as we have our own boats, and plenty of space to pile it; whereas, in the winter, there is always more or less trouble, in bad weather, in getting a regular supply of cars."

The above cases are all of more or less open combustion; but, as will be shown later, all coal, even though not perceptibly warm, is in a state of combustion for at any rate many months after it is mined, and this combustion, of course, means deterioration.

Trouble with coal cargoes at sea has materially decreased of recent years, largely owing to a decrease of length of time of voyages and an increase of knowledge; but on land, especially in Canada, trouble from the heating of coal is probably on the increase.

In all the great manufacturing countries, large concerns are more and more compelled to have large reserves of coal on hand. The admiralties carry coal stocks as a preparation for war; manufacturing firms to reduce the dislocation caused by strikes at the mines or in the carrying trades, or merely to tide over fluctuations in the price or supply of the coal they require.

Here in Canada the nature of our winter almost compels the storage of very large quantities of coal, especially at such places as Montreal, where coal can be obtained comparatively cheaply in summer by water, but where the railway freight necessary in winter renders the price almost prohibitive.

One railway company stacks from 200,000 to 250,000 tons of coal in Montreal alone each year, and the constant expense and trouble to which it is put to avoid fires, to say nothing of the loss due to the deterioration of

the coal, are enormous. Every railway company, every coal dealer, and every large consumer has also to store coal.

Enough has been said to show the great importance of the subject under discussion and also to show that any information that would in future result in reducing the losses on stored coal, even if only by one cent a ton, would be a valuable asset to the community.

The coal from the Hamstead colliery referred to above, being extremely apt to fire spontaneously, forms a good starting point in studying the question. Messrs. Haldane and Meachem have brought forward much interesting information in this connexion.[1]

They state that the mean temperature of the air at the foot of the shaft in the intake airway is 60° F. and in the return airway is 77° F. The natural temperature of the undisturbed strata at the level of the pit bottom is only 68° F., so that the whole of this rise in temperature of the air cannot be due to the natural heat in the strata; on the contrary, the strata is being gradually heated from the mine. "The coal behind an exposed surface gradually rises in temperature, month by month, and year by year. Thus at two places in the side of a main road, where the temperature at the end of 10 ft. boreholes was 66° F. in 1894 it had risen to 83° F. and 90° F. in 1898."

They calculate that every cubic foot of air passed through, removes one British Thermal Unit of heat from the mine; also that of this quantity of heat at the outside 7 per cent could be accounted for by the presence of horses, men, and burning candles, 10 per cent by the settling of the superincumbent strata, and 2 per cent by the friction of the air. This leaves over 80 per cent unaccounted for. "The only other possible source of heat in the mine is the chemical action of the air on the exposed coal and other material."

Temperatures were taken at different points in the airways and analyses made of samples of air taken at the same points. The analyses show that as the air passes through the pit it steadily loses oxygen and gains carbon dioxide, the average loss being $3 \cdot 13$ times the gain (in most collieries this ratio is said to be about $1 \cdot 6$). The following table, Table XX, clearly shows the intimate relation existing between the rise in temperature and the decrease in oxygen:—

TABLE XX

Temperature	Decrease in oxygen.	Temperature.	Decrease in oxygen.
55° F.	$0 \cdot 00\%$	78° F.	$0 \cdot 36\%$
71	$0 \cdot 16$	80	$0 \cdot 77$
73	$0 \cdot 25$	83	$0 \cdot 88$
74	$0 \cdot 37$	83	$1 \cdot 70$

The temperature of the air circulated through the mine does not rise steadily as it proceeds, because as it returns from the working face it

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[1] "Observations on the Relation of Underground Temperature and Spontaneous Fires in the Coal to Oxidation and to the Causes which Favour it," by J. S. Haldane, M.D., F.R.S., and F.G. Meachem, M.I.M.E., Trans. Inst. M.E., 1898, Vol. XVI, pp. 457-492.

is cooled from time to time by leaks from the intake airway, so that the foot of the upcast shaft is by no means the hottest place in the mine.

Haldane and Meachem have also made laboratory experiments on this coal in which they filled a quart sized flask with roughly powdered coal and left the flask sealed up in connexion with a mercury pressure gauge. They found that the pressure of the air in the flask steadily decreased for some time (unless the coal in the flask was very fresh, in which case the pressure first rises owing to the evolution of hydrocarbons), and an analysis of the residual gas then showed it to be almost pure nitrogen.

The following figures, Table XXI, show the course of such an experiment. The coal, which had been lying in lumps in the laboratory for three months after being mined, was crushed in a mortar and left lying in a thin layer (to allow any gas to escape) for two hours before putting into the flask. The temperature of the flask was about 54° F.; the pressure readings were corrected for changes of temperature and barometric pressure.

TABLE XXI.

Time since closing flask.	Negative pressure of mercury.	Time since closing flask.	Negative pressure of mercury.
1 hour....................	0·15 inches	4 days................	5·05 inches
5 hours....................	0·65 ,,	5 ,, ...	5·45 ,,
12 ,, ...	1·25 ,,	6 ,, ...	5·75 ,,
24 ,, ...	2·00 ,,	7 ,, ...	6·00 ,,
36 ,, ...	2·80 ,,	9 ,, ...	6·10 ,,
48 ,, ...	3·40 ,,	11 ,, ...	6·10 ,,
56 ,, ...	3·85 ,,	24 ,, ...	6·00 ,,
72 ,, ...	4·30 ,,	6 months.............	5·85 ,,

The analysis of the gas left in the flask at the end is shown in Table XXII.

TABLE XXII.

Constituents	Percentage
Oxygen................	0·07
Carbon dioxide...........	1·28
Methane................	0·65
Carbon monoxide...........	0·04
Nitrogen................	97·96

This experiment shows, what had already been proved by Dr. Richters in 1868, that coal absorbs oxygen, presumably with the evolution of heat, as it was shown above that the decrease of oxygen in the air in the mine was accompanied by a rise in temperature.

Another series of experiments performed by Haldane and Meachem consisted in passing air at a measured rate through a layer of coal in a flask, the flask being immersed in a water bath the temperature of which could be kept constant at any desired heat. Samples of the air that had passed through the coal were removed from time to time for analysis. Table XXIII shows the results of two such experiments:—

TABLE XXIII.

Experiment I, with 0·92 pounds of finely pounded coal, sent from the pit 4 days previously and freshly pounded up.

Temperature of bath.	Time since coal was pounded up.	Rate of ventilation per hour.	Deficiency of oxygen.	Carbon dioxide increased.	Methane and carbon monoxide.	Oxygen absorbed per ton of coal and per hour.
°F.	Hours.	Cub. Ft.	Per cent.	Per cent.	Per cent.	Cub. Ft.
59	2	0·091	1·10	0·07	0·290	2·45
59	5	0·131	0·72	0·02	—	2·30
59	8	0·080	1·00	0·05	—	1·95
60	20	0·114	0·46	0·04	—	1·26*
101	25	0·114	1·29	0·05	0·075	3·58
108	29	0·114	1·48	0·12	0·100	4·11
125	32	0·103	2·18	0·10	0·110	5·59

* Ventilation left on for 12 hours since last determination.

Experiment II, with 2·7 pounds of pounded coal (same sample as used in last experiment) sent from the pit 3 months previously and fragments pounded up a few hours before the experiment.

Temperature of bath	Rate of ventilation per hour.	Deficiency of oxygen.	Carbon dioxide increased.	Methane.	Carbon monoxide.	Oxygen absorbed per ton of coal and per hour.
°F.	Cub. Ft.	Per cent.	Per cent.	Per cent.	Per cent.	Cub. Ft.
59	0·078	0·40	0·09	0·00	0·00	0·26
160	0·084	5·31	0·67	0·07	0·14	3·70

A sample of coal, from another pit, which had stood in lumps in the laboratory for about two years, was still found to absorb oxygen when pounded up.

Haldane and Meachem deduce the following important results from these experiments.

(1) The rate of absorption of oxygen by coal is proportional to the partial pressure of the oxygen present.

(2) The rate of absorption of oxygen is approximately doubled for every 30° F. rise in temperature.

(3) The rate of absorption of oxygen at any temperature decreases as time goes on; at 59° F. it falls to half value after 20 hours.

(4) The absorption of oxygen takes place on the surface, thus lump coal that had been exposed to the air for two years would absorb more oxygen when fresh surface was exposed by crushing.

The experiments, by which the numerical values given are deduced, are open to criticism, but in any case these figures would vary with every different sample of coal. The general conclusions, however, are probably correct and bearing these in mind we can now go on to study the conditions existing in coal piles.

A pile of coal is in itself a very poor conductor of heat. This is shown by the fact that snow has been known to remain a whole year under a coal pile. The writer has heard of coal, stored during the winter in Cape Breton, brought up to Montreal during the spring or summer and rebanked, still having Cape Breton snow mixed with it when it was dug out of the pile in Montreal. Again, it is customary to test the temperature of a coal pile by means of iron rods pushed down through the coal; it has not infrequently happened that fire has been detected in a pile within 3 or 4 feet of a cool rod. We can, therefore, neglect the heat conductivity of the coal itself and assume that the only way in which heat generated in the pile can escape is by means of air currents. Again, on account of its low conductivity, after once a coal pile has been made the atmospheric temperature can have little effect below the surface except through air currents.

We will now consider a coal pile through which there is a slow circulation of air.

Then:—(1) Unless the surfaces exposed are already oxidized, oxygen will be absorbed from the air by the coal and heat will be evolved.

(2) Unless the heat of oxidation is carried away by the air current as fast as it is generated, the temperature of the coal will rise.

(3) As the temperature of the coal rises its rate of oxidation increases, that is, heat is generated more rapidly, so that the hotter the coal is, the more rapidly it tends to get hotter still, unless some secondary effect comes into play keeping it cool. The increase of rate of oxidation with increase of temperature will vary with different coals and although the velocity of oxidation may not be doubled for every 30° F. rise, as is said to be the case with Hamstead coal, the rate of increase is undoubtedly rapid. In the case of chemical reactions where the reacting substances are in intimate contact, as for example in solutions, the velocity of reaction approximately doubles for every 18° F. rise in temperature.

(4) As the temperature of the coal rises, the number of its constituents that can oxidize with noteworthy speed is increased.

(5) At any given temperature the rate of oxidation of the coal, that is, the rate of evolution of heat, will decrease as time goes on; this being due, of course, to the gradual completion of the oxidation of the readily oxidizable constituents of the coal.

(6) The higher the temperature and the more rapid the oxidation, the greater the air current will have to be to supply the necessary oxygen. At the same time, the higher the temperature at any spot in a coal pile is above the rest of the pile and the outside air the more convection currents will be set up. A warm spot in a pile may thus cause its own cure by setting up convection currents sufficient not only to supply the oxygen being absorbed, but also to carry away the heat faster than it is being generated, and in this way to cool the spot.

Generally, after a coal pile has been built, the temperature at any place inside the pile slowly rises, the oxidation of the fresh coal being com-

paratively rapid; after a while, owing to the gradual completion of the oxidation of the surface exposed and to the cooling effect of the convection currents, the rise of temperature comes to an end and the coal begins to get cooler, ultimately reaching atmospheric temperature. Occasionally, however, the first rise in temperature will take the coal above what may be described as the critical temperature; the oxidation is then so rapid that the retarding and cooling influences are insufficient, and the coal goes on getting hotter and hotter until it is in open combustion.

A coal pile is more likely to catch fire if:—

(a) The coal is an easily oxidizable one.

(b) The surface of coal exposed is large.

(c) Air is supplied at a rate sufficiently fast to supply the required oxygen but no faster.

(d) The heat generated cannot readily escape, and

(e) The initial temperature is high.

We will now proceed to consider these conditions. (a) is confirmed by Prof. Fischer of Göttingen, who states that coals which rapidly absorb bromine are those which are most liable to rapid oxidation and spontaneous ignition. He recommends, as a practical test, shaking one gram of the finely ground coal with 20 c.c. of a half normal solution of bromine for five minutes. If the smell of bromine has then disappeared, the coal is liable to oxidize rapidly and is not a safe one to store. Prof. Lewes states that a coal that gains more than 2 per cent in weight, when heated to 250° F. for three hours, is dangerous.

(b) As was shown before, the oxidation of the coal is a surface action, and the more surface there is exposed the more rapid is the action. Piles of lump coal rarely, if ever, catch fire; the danger is with run of mine or slack coal in which the surface exposed is so much larger in comparison with the weight. On shipboard, fires usually begin in the pile of broken coal formed under the hatches during loading. It is well known that cotton waste soaked in oil is liable to catch fire. There is in this case a large surface of the oxidizable material exposed in comparison with its weight.

(c) and (d). These conditions are most likely to be met with in a large pile. Inside such a pile it is not easy for the heat to escape, and although in one spot the air circulation may be too rapid and in another too slow, the probability of the circulation being just right in some place is greatly increased. The increase of danger with the height and size of the pile has been repeatedly proved. The most striking proof has been supplied by H. Fayol.[1]

An account of H. Fayol's excellent work at Commentry, in France, will be found in Prof. Threlfall's paper referred to above, or better still in the 1897 Report of the New South Wales Royal Commission.

Fayol built a pile of freshly mined Commentry slack coal, 40 metres long and varying in height from 6 metres to nothing. The pile was 1 metre

[1] "Etudes sur l'altération et la combustion spontanée de la houille exposée à l'air"—Bull. Soc. Industrie Minérale, Second Series, Vol. 8, 3rd part. 1879.

wide at the top. The temperatures were taken daily at eleven different points in the pile; the atmospheric temperature was also recorded. Fig. 3
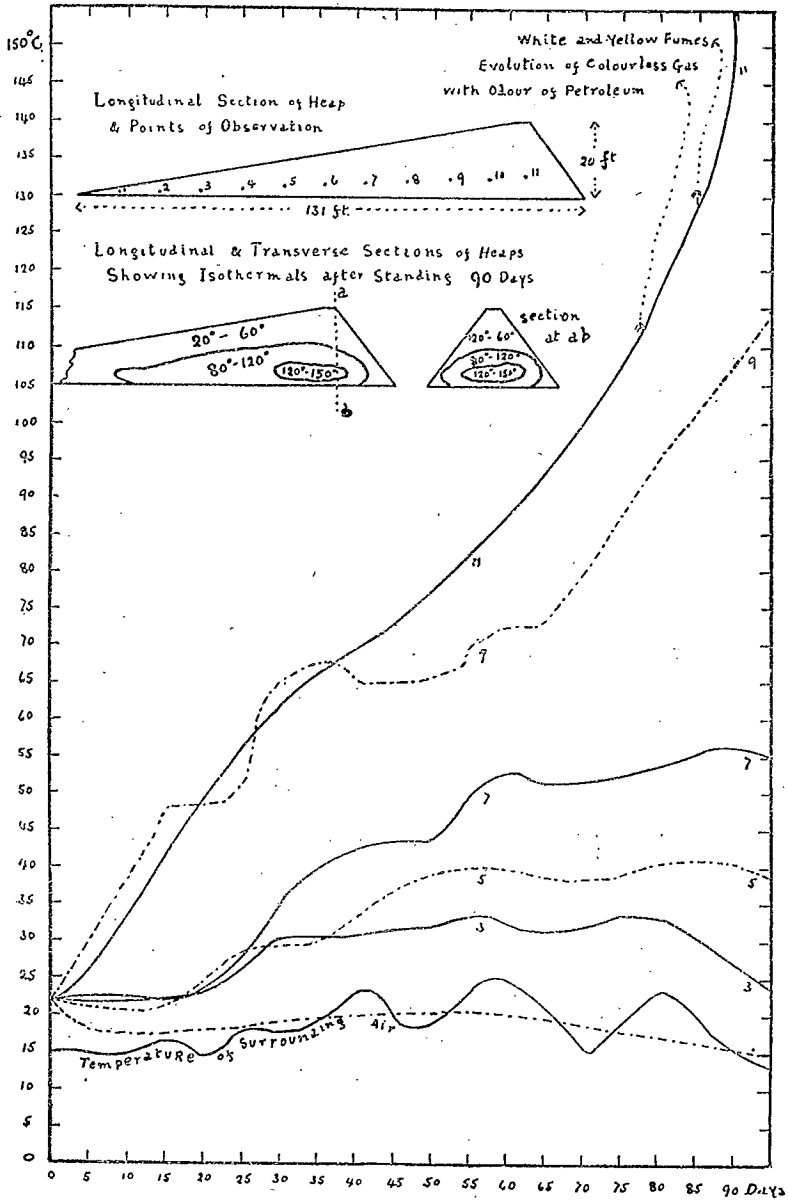
Fig. 3. Curves showing temperatures in coal pile.

shows: a section of the pile with the points of observation marked, the curves plotted from the daily temperature readings, for 90 days, at six of the

eleven points (the curves at the alternate points are left out to avoid confusion); the curve of the atmospheric temperature over the same period; and longitudinal and cross sections of the pile at the end of 90 days with isothermal curves plotted.

The curves show that rise of temperature increases with the height of the heap, and that the highest temperature occurs directly under the highest part of the heap and near the ground. In the thinnest part of the heap the coal rapidly cools from its original temperature and afterwards approximates to atmospheric temperature. Towards a height of 3 or 4 metres the temperature rises for a while and then falls again without ever passing 60° or 70° C. Where the heap is 4 metres high or over, the temperature continues to rise and ultimately the pile fires.

Fayol says: "From whatever part of the mine it comes, whatever may be its ash content, or the nature of the ash, coal piled up in the air heats in approximately the same manner and appears in its heating to follow laws which are approximately constant. Atmospheric influences—cold or heat, drought or damp—have not been sufficiently marked to be sensible."
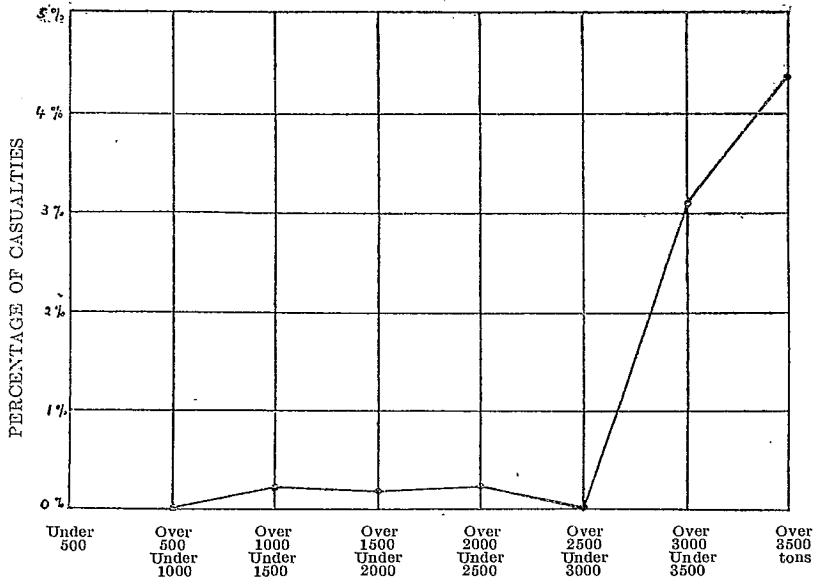
Fig. 4.   Curve showing relation between size of coal cargoes and liability to fire.

With Commentry slack coal no spontaneous combustion has occurred with heaps of less than 6½ feet high; but where the height exceeds 13 feet, spontaneous combustion nearly always occurs. This fact, that there is a danger height for any coal, above which it is not safe to build a pile of that coal, has been repeatedly confirmed.

The New South Wales Commission have shown this same point, of increase of danger with increase of size of pile, in a quite different way.

They have collected statistics of 2,149 shipments of coal, 13 of which fired or heated. Fig. 4 is a curve which shows the percentage of casualties plotted against the size of the cargoes. It is quite clear from this curve that with the coal and under the conditions that these ships were loaded, the danger of heating or firing increases very rapidly when the cargo exceeds 3,000 tons.

(e) The danger of an initial high temperature was first established by the New South Wales Commission. Their attention being directed to the epidemic of casualties during the hot summer of 1895–6, they were able to show clearly from their data that spontaneous fires in cargoes were associated with high maximum temperatures.

Prof. Threlfall has prepared, from data presented to the British Royal Commission of 1876, by E. Cooper Rundell, the curves shown in Fig. 5. The full curve shows the casualties from fire or heating for all ports of the United Kingdom, and for each month of the year, expressed as percentages of shipments of 500 tons of coal and upwards on voyages across the equator and through the Suez canal. The figures from which the curve is plotted cover a period of 3 years and are for 4,898 shipments with 102 casualties. The dotted curve shows the mean temperature throughout the year.
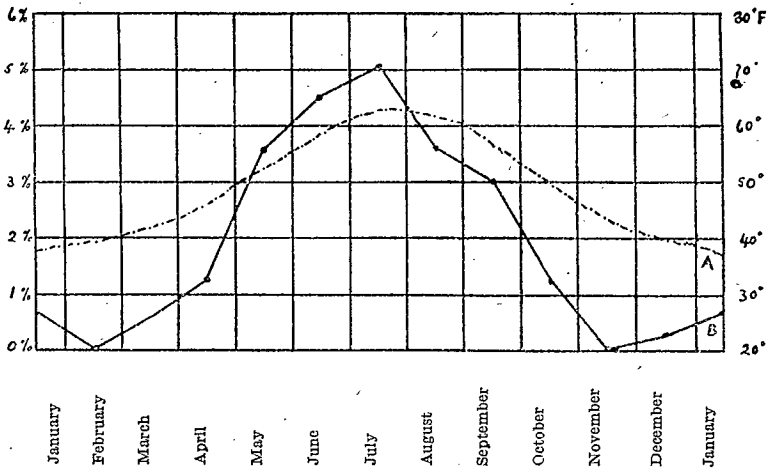
Fig. 5. Curve showing relation between time of lading of coal cargoes and liability to fire.

The intimate relation between the percentage of casualties and the temperature at the time of loading is beyond doubt.

It is not so easy to prove the same fact with regard to piles of coal on land. A coal pile is usually built gradually and with no record of dates or temperatures. The writer's attention was called to a coal pile which had heated rather rapidly, but which, having been built (in Canada) towards the end of September or the beginning of October, might have been supposed to have been cool to start with. Inquiries, however, had elicited

the fact that the coal was observed to be warm when unloaded from the steamer (estimated at 90° F.) although this had not been reported at the time.

One experiment by H. Fayol may be cited in this connexion. He showed that by heating the coal to a high initial temperature, which was yet well below its ignition point, it was quite easy to produce spontaneous combustion even in small piles of coal. This is perhaps the most conclusive experiment that has yet been made as to the influence of air on the spontaneous combustion of coal.

He made a conical heap of coal, containing from 70 to 100 cubic feet of coal, on the ground, surrounded with a ditch which could be filled with water. A cover was put over the coal, large enough to surround the heap and fit into the ditch, in such a way that the heap could be hermetically sealed from the external air. In one experiment the coal was heated to about 100° C. to start with. The cover was left in position, but some air holes with which it was provided were opened and shut and the temperature variations observed. When the holes were open the temperature rose, when they were closed it fell. By leaving the holes open for two days spontaneous combustion resulted ; the fire was put out by closing the holes and allowing the temperature to fall to 60° C.

Very little is known of the actual chemical compounds to be found in coal, although a great deal of work has been done on the decomposition products of coal when heated. Coal has been treated with acids, alkalies, ether, alcohol, pyridine and other solvents, and the extracts examined; but the results achieved have not been very great as yet. It is certain, however, that many coals contain unsaturated hydrocarbons and aldehydes, substances that are readily oxidized, the oxygen being added on to the molecule and not resulting in the formation or splitting off of carbon dioxide or water. Unsaturated compounds are detected by their power of absorbing bromine, as in Prof. Fischer's test described above. Aldehydes when oxidized produce acids; organic acids have been shown to be produced by the weathering of coal.

Although a great deal of work has been done on the weathering of coal the results are very difficult to summarize, classify, or discuss. Coals of all ages and qualities have been used and the weathering has proceeded under such variable and often uncertain conditions that very little can be deduced.

The chemical changes taking place in coal when oxygen is absorbed are easier to follow when proceeding more rapidly, that is, at higher temperatures. Dr. Richters of Waldenburg[1] heated 2 grams of a coking coal to 190° C. for 10 hours in a current of dry, carbon dioxide free air, and collected and weighed any water or carbon dioxide produced. He found that the coal gained 4·21 per cent in weight. The analysis of the coal before and after heating is shown in Table XXIV.

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[1]Dingler's Poly. Journal, Vol. 190, p. 398, Dec., 1868. Translations of several of Richters' papers are given in the Report of the New South Wales Commission.

TABLE XXIV

Coal dried in desiccator.	Heated coal.	104·21 parts by weight of the heated coal, containing, consequently
%	%	parts
Carbon...................86·82	82·19	85·65
Hydrogen................. 4·26	3·38	3·52
Oxygen (and Nitrogen)...... 6·40	11·96	12·47
Ash...................... 2·52	2·47	2·57
Total.................100·00	100·00	104·21

The coal accordingly lost by heating 0·74 per cent of hydrogen and 1·17 per cent of carbon, but gained 6·07 per cent oxygen. The water produced, however, corresponded to 0·66 per cent hydrogen, and the carbon dioxide to 1·25 per cent carbon. The result of the experiment is, therefore, to show that by heating the coal in air there is complete oxidation of the hydrogen and carbon which it loses.

Dr. Richters also showed that coal would absorb carbon dioxide as well as oxygen, and that its behaviour towards oxygen was materially changed by the absorption of carbon dioxide.

H. Fayol has done similar work on the oxidation of heated coal. He
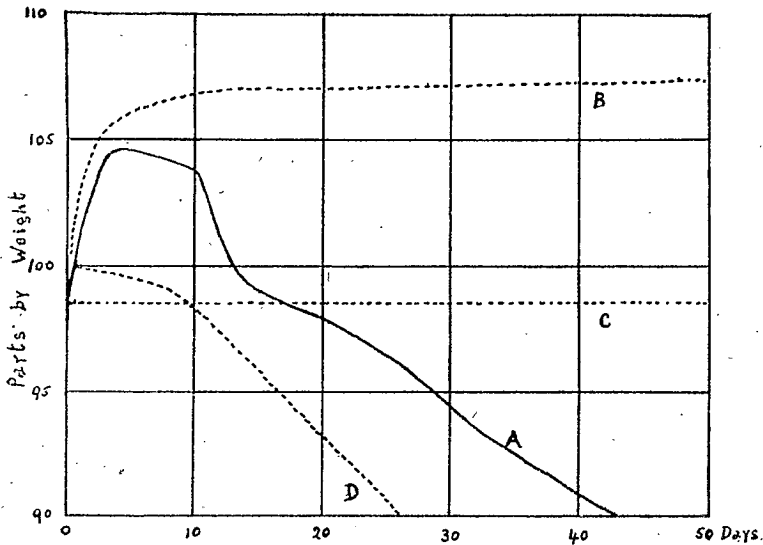
Fig. 6. Curves showing components of variations of weight of heated coal.

Components of the curve of variations of weight of Commentry coal, in powder, exposed to air at 200°C.
A=Curve of variations of weight, as observed.
B= " " " " " due to absorption of oxygen.
C= " " " " " due to loss of hygrometric water.
D= " " " " " due to loss by slow combustion.

continued the heating for a longer period and analysed the curve of variation of weight into its separate components. Some of his results are shown in Fig. 6.

TABLE XXV

Experimenter	Bedson (1)		Trowbridge (2)	Parr and Baker (3)					
Coal	A	A	B	C	C	D	D	E	E
Age of coal	Freshly hewn	Several months	?	Fresh drillings	Face sample 2 years	Fresh drillings	Face sample 2 years	Fresh drillings	Face sample 2 years
Weight of coal tested..........grams	?	?	296	261	209	220	205	231	108

PART I.—LAST PORTION OF AIR IN EXHAUSTION OF VESSEL

Time coal stood in vessel after closing and before exhausting, days			?	7	9	14	2	7	1
C.C. of gas per 100 grams coal	—	—	7.4	54.2	46.2	87.4	16.4	85.5	35.7
Composition of gas—									
Methane......%	Air of vessel was dis-		16.1	22.53	....	21.79	....	23.17	....
Carbon dioxide......%	placed by mercury be-		3.0	3.92	4.15	3.86	7.80	12.09	....
Oxygen......%	fore commencing the		22.5	5.30	4.46	1.04	15.50	1.11	22.20
Nitrogen......%	evacuation.		58.4	68.25	91.39	73.31	76.70	63.63	77.80
C.C. of oxygen + nitrogen per 100 grams coal			6.0	39.9	44.3	65.0	15.1	55.4	35.7
Deficiency of oxygen as % of O+N compared with 21.0% in air			−6.8	+13.8	+16.3	+19.6	+4.2	+19.3	−1.2

PART II.—GAS REMOVED BY VACUUM.

		Two fractions.								
Time coal stood in exhausted vessel for gases to be evolved, days	5	17	30	16	13	8	12	10	13	10
C.C. of gas per 100 grams of coal	18	14.5	16.2	21.3	10.31	7.12	22.18	1.08	11.26	1.02
Composition of gas—										
Methane......%	44.60	3.58	4.52	53.4	59.59	....	86.37	....	19.26	....
Carbon dioxide......%	1.65	1.18	0.64	7.0	17.85	80.50	7.58	....	32.09	54.60
Carbon monoxide......%				0.7						
Oxygen......%	8.99	23.80	20.91	3.2	4.83	1.30	0.61	....	7.32	9.90
Nitrogen......%	44.76	71.44	73.93	35.7	17.73	18.20	5.44	....	41.33	35.50
C.C. of oxygen + nitrogen per 100 grams coal	9.7	13.8	15.4	8.3	2.33	1.39	1.34	....	5.58	0.46
Deficiency of oxygen as % of O+N compared with 21.0% in air	+4.3	−4.0	−1.0	+12.8	−0.4	+14.3	+10.9	....	+6.0	−0.8

(1) "The Gases enclosed in Coal and Coal Dust," by P. P. Bedson, Trans. Inst. M. E., 1902, Vol. XXIV, p. 27.
(2) "The Gases enclosed in Coal and Certain Coal Dusts," by F. G. Trowbridge, J.S.C.I., 1906, Vol. XXV, p. 1129.
(3) "The Occluded Gases in Coal," by S. W. Parr and P. Barker, Bulletin 32, University of Illinois Engineering Experiment Station.

He finds that when coal is first heated in the air to 200° C. it rapidly loses its hygroscopic water; it also absorbs oxygen, thus increasing in weight, rapidly at first but more slowly after a while; but it also loses weight owing to slow combustion with the evolution of carbon dioxide and water; this is very slow at first but after about five days becomes quite rapid. The net result of these different changes is shown by the full curve: the coal first rapidly loses weight (to the extent of its water content) and then gains weight fairly rapidly for two or three days; it then loses weight very slowly for about seven days after which the loss of weight becomes quite rapid.

All these reactions which take place at high temperatures, in all probability also take place at ordinary temperatures, although much more slowly.

No figures showing the actual relation between the oxygen absorbed and the heat evolved seem to be available for any coal.

The oxidation of coal, as illustrated above by the work of Richters, Fayol, and Haldane and Meachem, might seem to be amply sufficient to explain the phenomena of weathering and spontaneous combustion. In spite of this, whether justified or not, there is a wide-spread opinion that some extra cause must be found to explain the firing of coal. Some writers appear to think that this extra cause must in itself be sufficient to heat the coal to its ignition point. This is a most improbable theory; it is far more likely that it is only necessary for the coal to be heated up to some temperature where it is still well below its ignition point, but where the oxidation of the coal becomes sufficiently rapid to ultimately heat the coal up to the ignition point.

Several different ways in which coal may receive an initial heating will now be considered.

(1) *Occlusion.* It is found that the metal palladium can absorb at ordinary temperature and pressure nearly 900 times its own volume of hydrogen. This gas does not appear to form an actual chemical compound with the palladium, but rather to be dissolved in it or possibly condensed on its surface; it is said to be occluded. When a gas becomes occluded heat is often given out.

Charcoal can occlude large quantities of many gases; the quantity of gas absorbed increases with the pressure and is approximately proportional to it. The quantity of heat given out during the occlusion nearly approaches that set free on dissolving the gas or by its passing into a liquid condition. Cocoanut charcoal, for example, will absorb nearly 100 volumes of carbon dioxide at ordinary temperature and pressure, about 150 calories of heat being generated for every gram of gas absorbed.

Freshly prepared charcoal that has been cooled in absence of air, is very liable to spontaneous ignition if exposed in large piles, this being due to the heat generated by the occlusion of the oxygen and nitrogen of the air. The actual oxidation of the carbon is probably negligibly small until a high temperature is reached. Here, therefore, is a case where the carbon is actually heated up to its ignition point by the heat of occlusion of gases.

Coal contains a high percentage of carbon, but that is probably all in the combined state. Coal certainly does not occlude gases to anything like the extent to which any of the common forms of charcoal do.

A large number of analyses have been made of gases extracted from coal, but the experiments are hardly conclusive.

When coal is first exposed during the working of a mine, hydrocarbons are always evolved, sometimes to a very great extent; this evolution often goes on for a considerable time and with a consequent reduction of the calorific value of the coal. There is no proof, however, that these gases were not mechanically enclosed under great pressure in the pores of the coal, whence they escape when the pressure is reduced. When the coal is exposed to the air, besides losing hydrocarbons, it absorbs oxygen and nitrogen, the proportion of the former being greater than in air. This absorption may be merely a diffusion of the air into the pores of the coal together with an oxidation of the coal by means of the extra oxygen. If this coal is now placed in a vessel and the gases pumped out, oxygen, nitrogen, hydrocarbons, etc., are obtained.

The crucial method of distinguishing between gas mechanically enclosed in the pores and occluded gas is that gas mechanically enclosed cannot occupy a greater volume, under the pressure at which it was enclosed, than that of the pores it occupies, whereas occluded gases can occupy a greater volume, for example, palladium, as mentioned above, occludes many hundred times its own volume of hydrogen.

We cannot test the way the hydrocarbons referred to above are held in the coal, as we have no means of knowing the pressure to which they have been subjected.

A few examples of gases extracted from coal, at ordinary temperatures, are given in Table XXV. These figures show that the total volume of oxygen and nitrogen known to be extracted from the coal is so small that it leaves the question as to whether the gases were occluded or mechanically enclosed uncertain. The difficulty of separating the gas out of the coal from the air in the containing vessel makes it impossible to even determine the volume of the former, unless the vessel is filled with water or mercury before beginning the extraction.

The large quantity of methane in fresh coal and the small amount left in coal that has been exposed to the air for some time is clearly shown in the table.

Bedson and, working under his direction, Trowbridge, frequently find the proportion of oxygen to nitrogen in the gas extracted from coal to be greater than in air; this would appear to be strong evidence for Bedson's claim that oxygen and possibly nitrogen, but proportionately more oxygen, were actually occluded by the coal.

Most experimenters, in all but a few of their experiments, find the proportion of oxygen in the gases extracted to be less than in air. As oxygen is known to be comparatively readily taken into combination by

the coal, this deficiency does not necessarily disprove Bedson's statement, rather the claim is confirmed by the fact that an excess of oxygen is occasionally found. If oxygen is occluded, and to an extent compared with nitrogen relatively greater than in its occurrence in air, the experiments just cited indicate that in the majority of cases the occluded oxygen combines with the coal so rapidly that there is a deficiency of oxygen in the gas which can be pumped out again.

The nitrogen is always in excess over the oxygen if the coal is heated before the gases are pumped out, oxidation being much more rapid at higher temperatures.

The conclusion arrived at, from the above discussion of evidence, is that the quantity of air occluded by coal is so small that the actual heat of occlusion cannot be important; but a secondary action must be considered in which the occluded oxygen is probably no longer negligible.

(2) *Oxidation Accelerated by Occlusion.* When two or more gases are occluded in the same substance, they are brought into such intimate contact with each other that they may combine with notable rapidity, although if they were mixed in the gaseous state combination would be inappreciable. Platinum black, gas and pipe lighters are well known examples of this type of reaction. The platinum black exposed to the air occludes oxygen; when it is brought into an atmosphere of coal gas or alcohol vapour these latter are also occluded, and coming into very intimate contact with the oxygen they are oxidized with such rapidity that heat is generated faster than it can be dissipated and the temperature rises to the ignition point.

Charcoal that has been heated to remove occluded gases and allowed to cool in an atmosphere of hydrogen sulphide, catches fire when placed in an atmosphere of oxygen. The oxygen combines with the previously occluded hydrogen sulphide, although if the gases be mixed under ordinary conditions no appreciable action results.

Freshly mined coal may be compared with the charcoal described above. The coal is saturated with hydrocarbons instead of with hydrogen sulphide, and exposed to the air instead of to oxygen; it is quite natural to expect that in this case also an accelerated oxidation will take place which, once begun, may easily result ultimately in the firing of the pile. Even if the coal has lost all its gaseous hydrocarbons, the occluded oxygen will be brought into such intimate contact with the readily oxidizable constituents of the coal that the same result will be reached.

Coal occludes gases to so small an extent that the action described above is not likely to heat it up to its ignition point, but may provide the initial heating for which we have been looking. For reasons already given, open combustion will result only in a large pile.

(3) *Oxidation of Pyrites.* That the spontaneous firing of coal is due to the heat generated by the weathering of the pyrites it contained, was one of the first theories advanced, and it is still widely held. Experts such as

Lewes and Threlfall now vigorously combat the idea that the pyrites do more than slightly assist.

The arguments brought forward by the two sides are somewhat as follows:—

Nearly all coal contains pyrites.

Pyrites is known to be oxidized by the air in the presence of moisture, heat being thereby generated. The reaction may be written as follows: $2FeS_2 + 2H_2O + 7O_2 = 2FeSO + 2H_2SO$, although it is probable that the reaction proceeds partially or altogether to the formation of ferric sulphate or basic sulphates. The pyrites may also decompose in such a way as to liberate sulphur.

The above reaction requires water, and wet coal is commonly supposed to be much more liable to fire than dry coal.

Coal mine waters often contain notable quantities of sulphuric acid, thus proving the weathering of the pyrites.

Coal heaps that have been exposed to the weather often have visible lumps of basic ferric sulphate, and ventilation holes in such piles are said to sometimes become choked up with the free sulphur deposited in them.

On the contrary, there does not appear to be any connexion between the amount of pyrites in a coal and its tendency to fire.

Laboratory experiments on the oxidation of coal show that coal takes up oxygen as well or better when dry than wet, which is the reverse of what would be the case if the pyrites was being oxidized, and that the amount of oxygen taken up is often greater than could theoretically be taken up by the complete oxidation of all the pyrites present.

Fires are frequently known to have originated in dry coal.

The heat of oxidation of pyrites is only small, weight for weight coal will evolve about four or five times as much heat by its complete oxidation. A more conclusive statement would be that a given weight of oxygen evolved more heat by combining with the readily oxidizable constituents of coal than by combining with the pyrites. This is probably true, but the writer is unacquainted with any work which has been done that would prove it.

Pyrites, by weathering, could hardly heat itself up to ignition point, much less the coal surrounding it; in fact, heaps of pyrites free from carbonaceous material are never known to fire spontaneously.

Prof. Lewes said that as pyrites can liberate sulphur, the ignition point of which is lower than that of coal, he at first thought that pyrites might cause danger by thus lowering the ignition point. He found, however, that sulphur oxidizes faster than it could be liberated, even at temperatures as low as 60° C., so that this danger cannot exist.

In considering these arguments we must remember that there are different varieties of pyrites, that known as marcasite weathering much more rapidly than the ordinary variety. The fine flakes of pyrites, some-

times scattered throughout the coal, are probably marcasite and certainly weather faster than the larger lumps.

A single match may ignite a pile of shavings, a single flake of marcasite might cause a warm spot that might result in a coal pile firing. This might explain the fact that the tendency for a coal pile to fire is not proportional to the percentage of sulphur or pyrites present.

We are not at present looking for something to heat the coal to its ignition point, but only to give it a little initial heating. If sulphur is liberated from pyrites and oxidizes (both actions being accompanied by an evolution of heat) at low temperatures, it might easily act as a starter, although the sulphur did not remain as such to lower the ignition point.

The crucial question seems to be, does the coal or the pyrites generate heat the faster by its normal oxidation at low temperatures? The evidence seems to be strongly in favour of the answer: the coal. This would thus rule pyrites out of account as the usual cause of fires. It is, of course, always conceivable that under certain circumstances this might be reversed and the pyrites blamed; but this probably seldom or never occurs.

On one point all parties are agreed. When flakes of pyrites weather they expand and fracture the coal, and thus expose more and fresh surfaces for oxidation and indirectly increase the danger of heating. As a general rule, however, this breaking must be slight compared with that caused by handling, although it will certainly assist in the deterioration of the coal.

(4) *The Action of Water.* This is an even more knotty point than the preceding one. On the one hand we have scientific evidence to prove that coal oxidizes less when wet than when dry, and on the other an almost universal and deep-rooted opinion, amongst men of practical experience of the storage of coal, that wet coal is dangerous. .

The scientific experiments of Richters and others must carry conviction as far as they go; at the same time it appears dangerous to assume, without the very fullest proof, that the opinions of the practical men are simply the relics of an old superstition, bolstered by forgetting facts that appear to contradict and only remembering confirmatory facts.

A British Royal Commission on coal investigated this problem in 1876. The Commissioners said : "Most of the witnesses who have come before us have strongly condemned the shipment or carriage of coal in a wet condition, and their experience in this respect is, to a certain extent, supported by the scientific evidence. . . . It would appear that the wetting of certain kinds of coal, more especially those containing pyrites, is active in promoting spontaneous combustion; but the statements of some of the witnesses lead to the impression that moisture has been credited with cases of combustion beyond the sphere of its operation; while from other passages of the evidence, it appears to us that the influence of the water, existing to a greater or less extent, in all coal before it has been brought to the surface, has not been sufficiently recognized."

The two scientific experts of the Commission, Dr. Percy and Professor

Abel, said, "Spontaneous ignition of coal, when due to the oxidation of the porous and readily oxidizable carbonaceous substances occurring in coal, does not appear to be favoured by the presence of water in the coal or by its access to a cargo; on the contrary, these portions by becoming wet, would have their pores more or less filled with water, and their power of absorbing oxygen would be proportionally diminished, hence the presence of water must be antagonistic to the action of the latter in many instances, though, when iron pyrites is present, it may promote or accelerate spontaneous heating, as already pointed out."

In spite of the quotations above, the report of the Royal Commission of 1876 seems to have been taken as condemning the shipment of all wet coal. The King's Regulations and Admiralty Instructions, Article 523, paragraph 25, read: "Coal should not be taken on board wet, as moisture sometimes causes a rapid and dangerous generation of heat and gas. . . . Coal should always be kept as dry as possible." This paragraph has, however, since been rescinded.

The New South Wales Royal Commissioners stated in their Report of 1897 that: "It must still be regarded as an open question, however, whether the heating of Newcastle coal is in any way dependent on the amount of moisture which it contains. On the one hand, we have the very definite experimental result of Fayol that moisture has no influence whatever on the liability to spontaneous combustion of the coals of Commentry, and, on the other, we see that the disintegrating action of oxidizing pyrites may have an indirect effect."

It may here be stated that the effect of water in disintegrating pyritic coal is always conceded, although many persons hold that except with highly pyritic coal it is not very important.

The N.S.W. Commission after making the first report, carried out a further investigation to determine the effect of water upon stored coal. Two large wooden bins were built and both filled with slack coal under as nearly identical conditions as possible except that in filling the one the coal was kept dry and in the other was thoroughly wet during loading by water from a hose. The wet coal was found to be 10° C. cooler to start with, and, although it heated slightly at first, after 46 days the mean temperature in this bin showed a steady decline that continued until the 139th day, when the temperature readings were discontinued. The dry coal, on the contrary, grew steadily, although at first slowly, hotter, and after 63 days the bin had to be flooded and the heated coal dug out in order to avoid a fire.

The 1900 report says that to the question the Commission set out to solve, therefore, they return "a direct and unconditioned answer. Coal is less liable to spontaneous combustion when it is loaded wet than when it is loaded dry."

The report disposes of the findings of the 1876 Commission as follows: "The British Commission received 26 answers to the effect that wet coal was the more dangerous. But an analysis of the evidence discloses

that 25 of these answers were based on 'general impression' or hearsay evidence only, while the 26th was not tested by cross examination. The opinions referred to were held, not by scientific men, but by those engaged in the coal trade. . . . All such views, it seems to us, must now be definitely abandoned."

A case in confirmation of these views is that of the sailing ship *Strathdon* which sailed with coal from Newcastle, N.S.W., on June 16, 1900, arriving at San Francisco on August 25. It rained very hard whilst some of the coal was above ground awaiting shipment, and the coal became so thoroughly wet that water ran out of the trucks during loading; this wet coal was charged into holds 2 and 3, whereas holds 1 and 4 were filled with perfectly dry coal. The holds were 23·6 feet deep, temperature tubes 22 feet long were inserted into the body of the cargo through the hatchways and the temperatures were regularly taken and recorded in the log-book. The air temperatures were 62° F. at start, 92° at the equator, and 72° at discharge. In the dry holds the temperatures were 74° F. at start, rising to 94° and 92°, and falling to 94° and 84° at discharge; in the wet coal the corresponding temperatures were 62° F., maximum 77° and falling to 74° and 75° at discharge. The maximum temperature difference was 22° F. and the average 13·8° F., the wet coal being the cooler.

On the other hand, V. B. Lewes cites the case of a ship carrying a cargo of coal, where the main hatch was filled in dry weather and the after hatch whilst it was raining. After a few days the temperature was about 10° F. higher in wet coal than in the dry, spontaneous ignition being the ultimate result.

Prof. Lewes' opinion is that at first external wetting retards the absorption of oxygen, but that the presence of moisture afterwards accelerates the action of the already absorbed oxygen upon the hydrocarbons; he draws a sharp distinction between wet coal and damp coal, it being the latter that he considers dangerous.

Enough has now been said to show the complexity of the subject. Before proceeding further with its discussion it will be well to define what is meant by dry coal. Coal as taken from the mine, or that has been exposed to rain, contains water that it gives up when exposed to dry air; when it no longer loses weight it is said to be "air dry." If air dry coal is ground up and subjected in a thin layer to a temperature of 105° C. for one hour, it loses a further quantity of water and is now said to be "dry." This definition of dry coal is quite empirical, it would be very rash to assume that the coal is free from water, it certainly contains the elements of water and can readily be made to give up actual water. Dry coal, in questions of handling and storage, usually means air dry coal.

It is probable that water was first blamed for the spontaneous ignition of coal, on account of a false analogy with the heat produced by the fermentation of damp hay. Further, it is sometimes noticed that the top of a coal pile feels warm the day after a shower of rain. The obvious explana-

tion of this is not that the water causes the coal to heat, but is, as suggested by the New South Wales Commission, that the pile was already hot inside; the water trickling down came to the hot coal, was turned to steam, and rose to the surface where its warmth was felt.

It is often pointed out that many chemical reactions that take place readily or even violently under ordinary conditions, will not take place at all if the reacting bodies are exceedingly dry. This is no argument, however, in favour of the danger of storing wet coal. The amount of water needed for such reactions is so very small that certainly all air dry coals, and probably all dry coals, contain far more than is necessary for any chemical action in which water is merely an accelerator and is not one of the reacting bodies, as in the weathering of pyrites.

Richters has carried out experiments upon the rates of oxidation of damp and of air dry coal. He showed that not only does the air dry coal absorb oxygen faster than the damp coal, but by putting some calcium chloride into the vicinity of the former, so that it becomes still dryer, its rate of oxygen absorption is further increased.

Coal immersed in water, being practically protected from the oxygen of the air, is subject to little or no deterioration. It was, therefore, natural to expect that wet coal would also be considerably protected from oxidation, but there was the possibility that damp coal might be worse than either wet or dry coal. Richters' results, if generally true, clearly show that this is not the case, dry coal being most readily oxidized. Experiments are being carried out to test this point by the University of Illinois (see Bulletin 17) and the University of Missouri (see Bulletin 1). The results of their work, which is not yet completed, can so far hardly be said to confirm or disprove Richters' conclusions.

The writer's own opinion is that water always retards the oxidation of coal, except in its effect on pyrites, but that indirectly it may have a marked influence for good or for bad on the condition of stored coal. Some of these ways in which the coal is influenced are well known, others are here put forward as tentative suggestions.

(a) Fayol has stated that by building up a coal pile in thin layers, allowing sufficient time for the first rapid oxidation of each layer of coal to take place whilst the heat generated can be easily dissipated into the air, before covering with another layer, a coal pile can be safely built to any height. Generally coal will be partially oxidized before storing and the danger thus be reduced; but if coal is taken wet from the mine, or is wet soon after mining, and is stored still wet, this preliminary oxidation is largely prevented. The coal afterwards drys out and the first most rapid and energetic oxidation takes place in the pile where the heat accumulates and danger results.

(b) A warm coal thoroughly wet by rain or by deliberate spraying will be cooled by the water itself and also by its subsequent evaporation. The coal is thus, as in the New South Wales bin experiment, cooler than it

would have been dry and the initial temperature being lowered the danger is reduced.

(c) It has already been stated that in coal cargoes fires almost always begin in the cone under the hatchway where the small broken coal accumulates and where there is consequently the largest proportion of surface exposed for oxidation. When dry coal is dumped there is the same tendency for the small coal to settle into a compact mass towards the bottom where, unless it is too compact to allow the air to circulate, there will be similarly the greatest danger of heating. When coal is wet the dust and small particles cling together and adhere to the larger lumps, so that a pile built of wet coal is likely to be more homogeneous from top to bottom. This difference in the mechanical distribution of the coal may easily make a great difference to its tendency to fire; it is possible that in some cases the danger is thereby increased and in other cases decreased.

(d) After a pile has been built, if it is exposed to heavy rain the dust and fine coal are washed down and form a dense layer 1 or 2 feet below the surface. This also must have a great effect on the air circulation through the pile and consequently on its tendency to fire. If the circulation was previously too rapid for serious heating, the danger will be increased; if too slow, it will be made still slower and the danger of ignition will be decreased.

If these views are correct, water is a preservative for all coal except the pyritic, but that wetting the coal before or after storing may do much good or may do much harm. It is probable that when our knowledge of the air circulation and rate of oxidation in coal piles is increased, water will be a good servant; at present it is a dangerous ally.

(5.) *Heat of Oxidation of Bituminous Shales.*—Bituminous shales from the coal seams often fire as easily, possibly more easily, than the coal itself. It is said that in cases of trouble with Cape Breton coal in Montreal, a piece of shale is usually found in the centre of the heated portion; but this may be merely a coincidence. The problem yet to be solved is—does the pure coal or the shale oxidize and evolve heat the faster at ordinary temperatures.

(6.) *External Heat.*—The initial heating may be the result of boilers, steam pipes, or flues near to the coal, or of cotton waste, which if soaked in some oils oxidizes readily, and which if allowed thus to get into a coal pile might easily cause a hot spot. Again, where wood comes in contact with coal it is often noticed that the fires begin in close proximity to the wood. This may be due to heat evolved by the rotting of the wood or to some modification of the air currents caused by the wood.

(7.) *Heat of the Sun.*—It has been shown above that the hotter the coal when stored the greater is the danger, coal being black absorbs the sun's rays readily and may easily reach a temperature considerably above the shade temperature at the time. If coal when on a car before dumping, or on the surface of a pile, becomes heated by the sun, and if the warm portion

is then buried under more coal, a fire may easily result. This appears to be a case where a judicious spraying with water would prove a safeguard.

The New South Wales Commission made some experiments and found that on seven successive days the maximum temperature 3″ or 4″ below the surface of some coal exposed to the sun varied from $25 \cdot 6°$ F. to $36 \cdot 8°$ F. higher than the maximum shade temperature on the same days.

It seems to be doubtful whether most coal piles are prevented from firing by an excess or a deficiency of air. Fires in ships begin under the hatchways where, it is true, the most air might be expected, but they begin in the cone of fine coal where the circulation can only be slight. The remedy would, therefore, seem to be to increase the ventilation; but, on the contrary, this is found in practice to be the worst thing to do. Fires in coal piles generally begin near the bottom away from the air, and yet again ventilation is said to be dangerous. Thorough ventilation would certainly prevent fires in either case.

V. B. Lewes says that for ventilation to do any good, cool air would have to flow continuously and freely through every portion of the coal. Steam coal, he says, will absorb twice its own volume of oxygen in ten days under favourable conditions. A ton of such coal occupies 42 or 43 cubic feet, of which 12 cubic feet is air space, a ton will, therefore, absorb 60 cubic feet of oxygen in ten days, which represents 300 cubic feet of air or 25 times the volume of the air contained in it; that is to say, if these figures are correct, there would have to be a complete change of air every ten hours.

It is difficult to understand how air can circulate through a large pile of slack coal, it looks to be almost impossible. The air does not appear to come in through the sides of the pile as fires occur indiscriminately near the sides or in the centre and their position is not apparently affected by the direction of the wind. One possible explanation is that inequalities of temperatures in the pile cause convection currents, air descending from the top in some places and ascending in others. Two or three somewhat casual inspections of a large pile ventilated with a large number of vertical holes passing from top to bottom, failed to anywhere discover a down draught, warm air appeared to rise from all the holes, and in winter when the pile was covered with snow melted passages through to the surface.

Gaseous diffusion must always cause a circulation of air through a coal pile; but as oxygen, which is denser then nitrogen, is absorbed by the coal the residual air inside the pile becomes lighter than that outside and the normal rate of diffusion is thereby accelerated. Changes of barometric pressure will also effect a slight air circulation through a pile; when the pressure is low not only will the air in the interstices expand, but air dissolved in water in the coal, and occluded gases, will also be given off, since the amount of gases dissolved or occluded is proportional to the pressure; when the pressure increases there will be a flow of air back into the coal to fill up interstices, to dissolve in the water and to be occluded. The amount

of such air currents up and down will be greatest at the surface and decrease steadily downwards; the circulation best suited to cause fires might, therefore, be expected to occur at a depth proportional to the height of the pile; as a matter of fact, fires usually occur about two-thirds of the way down. We have so far assumed that the ground on which the pile rests is impervious, but if it is a light sandy soil the surging of the air up and down with barometric changes will take place not only through the pile but also through some of the soil below. The amount of air passing through the coal from this cause will be thus increased, and, together with the air circulated by other causes, may be too great to cause a fire even at the very bottom of the pile. This idea is in accordance with the fact that coal piles give more trouble on wet clayey soil than on dry sandy soil, but it has been suggested to the writer that the rising and falling of surface moisture in the soil are more likely than barometric changes to cause a cooling air circulation through the coal. Those who believe in the theory that wet coal is dangerous say that coal fires on a clayey soil because it remains damp owing to the poor drainage.

Whatever the explanation, it at any rate appears certain that it is well to store coal on well drained ground; a thick bed of cinders is often used as a foundation.

It is just possible that some coals contain enough occluded oxygen when stored to allow a considerable amount of oxidation to take place without any access of fresh air. Parr and Hamilton [1] find that samples of coal deteriorate in even the most carefully sealed containers. They examined some coal that had been unopened in an air-tight jar for three years, a lot of the pyrites was found to be oxidized to ferric sulphate, this was leached out and determined, and it was found that the oxidation which had been accomplished corresponded to $1 \cdot 99$ grams, or $1 \cdot 39$ litres, of oxygen, equivalent to 7 litres of air. The coal was buckwheat size, filling a pint jar three-fourths full. This result is hard to understand when compared for example with Parr's own figures showing the small amount of oxygen occluded in coal: but it is possible that the iron pyrites was oxidized at the expense of oxygen compounds in the coal. Details of the experiment are not given—if water containing dissolved air was used, or if the coal was occasionally allowed to come into contact with the air during the leaching process, it is possible that much of the recorded oxidation took place during the leaching process and not in the bottle.

Fayol's experiment described on page 105 does not, as might be supposed, prove that coal cannot heat with occluded oxygen alone. When he cut off the air supply the coal certainly cooled, but it was then over 100° C. and any occluded oxygen would have already combined with the coal below that temperature. Coal may heat with occluded oxygen, but as it gets hot fresh air must be supplied or it will cool again; such hot coal will, however, tend to draw in the fresh air required by means of convection currents.

[1] "The Weathering of Coal," Bulletin 17 of the University of Illinois Engineering Experiment Station.

If iron pyrites and the oxygen compounds of coal can react, it suggests that possibly also fresh coal and weathered coal may react and thus make a dangerous mixture. There is no clear evidence on this point; Fayol says that coal spread in successive layers of not more than 3 feet and with a lapse of time after each layer before putting down the next, forms a safe pile. Other writers say that coal once heated and cooled never heats again, and yet, the foreman of a coal yard in Montreal states that mixtures of old, heated and cooled, coal with fresh coal are very dangerous; and a case has been cited where in building a coal pile banking was stopped for a month and then continued, fires afterwards broke out all along the line of contact of the old and the new coal. These fires might be explained as being due to mixing, or possibly, the surface of the old coal was strongly heated by the sun when the new coal was put on the top. Coals from certain seams are said to keep cool when stored alone but to heat when stored together.

Coal is banked near the mines in Cape Breton in piles of 20 or even 30 feet high without a sign of heating, the same coal stored in Montreal heats in less than three months in piles of only half the height. This is probably because the coal in Cape Breton is in comparatively large lumps, comes straight from the mine saturated with hydrocarbons, and is stored in winter and, therefore, cold; whereas the coal in Montreal is more broken up and almost like slack, is saturated with air rather than with hydrocarbons, and is stored in summer and, therefore, often hot.

Remedies for trouble with coal piles are easy to suggest, but are often difficult and expensive to carry out. Storage under water has been successfully tried by the British Admiralty and others, and the former has also shown that coal briquettes can be stored without serious loss even in hot climates. Continuous storage under water could not easily be adopted in Canada, as in winter when the coal was wanted the water would be frozen; but it would probably be practicable to so store in a cement tank from which the water was drained in the autumn when it was reasonably cold.

Very few coals will heat if stored in piles of less than 10 feet high and a thicker pile can be safely made if it is very thoroughly ventilated. Fayol's suggestion of building up a pile in thin layers might be tried, or Threlfall's recommendation of spraying. Where fine coal can be used, as for example where coal dust firing is employed, the coal can be screened as received, the screenings used for immediate consumption and only the lump coal stored; as has already been stated piles of lump coal rarely, if ever, catch fire.

Plate I shows a general view of a ventilated coal pile of the Canadian Pacific Railway Co. near their Angus shops at Montreal; and Plate II is a nearer view of the same pile showing the openings of the ventilation holes, which holes pass from top to bottom of the pile. Plate III shows an unventilated coal pile on fire in Montreal.

PLATE I.

Ventilated coal pile at Montreal.   General view.

PLATE II.

Ventilated coal pile at Montreal.

PLATE III.

Unventilated coal pile on fire in Montreal.

The question is largely one of dollars and cents. A cement tank involves a large capital outlay; but with proper handling machinery the coal need hardly cost as much each year for storing as it would in an ordinary stock pile. A ventilated pile requires no capital beyond the handling arrangements also required for the unventilated pile; but the annual outlay in providing vent holes is considerable. Coal stored under water suffers no appreciable deterioration chemically or physically. Stored in air but kept fairly cool it may lose 5 per cent in value—authorities differ very much on this point; coal which heats although it does not actually fire, may lose up to 20 or 25 per cent of its value, and an actual fire may involve great expense to extinguish it, in addition to the damage to the coal. In any particular case the outlays involved and the economies effected must be considered in deciding between the different methods of storing. It is, however, greatly to be deplored that the coal resources of the country should be needlessly wasted by spontaneous combustion.

After this paper was written but before it was first printed in the Journal of the Canadian Mining Institute, an account of further work of the University of Illinois Engineering Experiment Station was published—Bulletin No. 38, "The Weathering of Coal, Series of 1909," by S. W. Parr and W. F. Wheeler. The conclusions from their experimental work are as follows:—

"Coal of the type found in Illinois and neighbouring States is not affected seriously during storage when only the changes in weight and losses in heating power are considered. The changes in weight may be either gains or losses of probably never over two per cent in a period of one year. The heating value decreases most rapidly during the first week after mining and continues to decrease more and more slowly for an indefinite time. In the coals that have been tested, one per cent is about the average loss for the first week and three to three and one-half per cent would cover the losses for a year, although in some instances the loss was found to be as high as five per cent in a year.

"The losses due to disintegration of the coal and to spontaneous ignition seem to be of far greater importance than any changes in weight and heating value although they cannot be expressed in figures for comparison. The storage of coal of a size larger than is to be used would overcome part of this objection to storage, as the coal would be crushed to the most advantageous size just before firing, the larger sizes of coal are also much less liable to take fire spontaneously. Storage under water will prevent disintegration of the coal to a very large extent, and it will absolutely prevent any fire losses. Aside from these advantages in favour of storing coal under water, there seems to be very little to be said in favour of any particular method of storing coal."

A coal pile should always be regularly tested until the probable period of incubation is past or until the temperature having first risen begins to steadily fall again. The simplest method of testing is by means of iron

rods run down through the pile at frequent intervals; these can be seen in Plate II. They should be pulled out once or twice a week, their temperature being felt along their length, and then put back in a fresh place. If dangerous heat develops in a ventilated pile it is best treated by making extra ventilation holes; if this does not succeed, or in the case of an unventilated pile, it is well to dig away the hot coal and spread it out to cool. Digging out is also the best remedy in case of fire. It is well to begin by digging all round the heated spot to isolate it, as otherwise it may spread back into the rest of the pile as air gets to it.

Water is not found to be successful in extinguishing fires. In the first place the coal above the fire cokes and thus armours the fire over and the water cannot readily penetrate through. Cases have been known where in digging out ships' cargoes, hollow spaces were found near the bottom containing only ashes; a fire had begun, armoured itself over and burned out without its presence having been suspected. Secondly, water may cause the fire to spread, as the steam generated passing through the pile heats up fresh coal which also soon fires. Fayol showed that coal, even in small piles, soon fired if first heated to 100° C.

The subject of spontaneous combustion is a very large one and this paper comes far short of covering even the work already done; but it will at anyrate serve to indicate the incompleteness of our present information.

In conclusion, the writer wishes to thank Dr. Porter for his great assistance in obtaining references and papers, and for the photographs, and to thank him and others for their valuable information, criticisms, and suggestions.