

Privy Council

MEDICAL RESEARCH
COUNCIL

CHRONIC PULMONARY DISEASE IN
SOUTH WALES COALMINERS

II.—ENVIRONMENTAL STUDIES

A.—REPORT BY THE COMMITTEE ON INDUSTRIAL
PULMONARY DISEASE.

B.—G.—REPORTS ON PHYSICAL, CHEMICAL AND
PETROLOGICAL STUDIES by T. Bedford and
C. G. Warner; H. V. A. Briscoe, P. F. Holt,
N. Spoor and others; G. Nagelschmidt; A.
Brammall and J. G. C. Leech; D. Hicks and
G. Nagelschmidt; J. Ivon Graham and D. F.
Runnicles; and co-workers.



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The late Dr. D. A. POWELL was also a member of the Committee during the period of these investigations.

PREFACE

This Report deals with the environmental aspects of the investigation of chronic pulmonary disease in South Wales coalminers which the Medical Research Council undertook in 1936 at the request of the Home Office and the Mines Department. It is thus complementary to the Report on the medical survey and related pathological studies which was issued last year (*Spec. Rep. Ser. Med. Res. Coun., Lond., No. 243, 1942*). The whole scheme of inquiry has been directed by the Committee on Industrial Pulmonary Disease, who have provided covering reports (Sections A of *Spec. Rep. Ser. No. 243* and of the present monograph), reviewing and summarising the conclusions of the individual investigators.

The medical survey showed that the pulmonary abnormality encountered among South Wales coalminers was not restricted to the anthracite area, but could be found in the whole of this coalfield; its incidence and severity were greatest, however, among colliers who had worked for long periods at the coal-face in anthracite mines. A relationship was established between the incidence of pulmonary abnormality among the colliers, as judged by X-ray evidence, and the rank of the coal mined at the different collieries, though within the anthracite area there were also distinct local variations in incidence. Furthermore, the results of the medical survey and the pathological studies established that the types of pulmonary abnormality in South Wales coalminers included a form of disabling pulmonary disease which did not come within the accepted definition of "silicosis" as used for the purposes of the workmen's compensation schemes. Both this condition ("dust reticulation"), and the more developed nodular and conglomerate radiographic changes also seen typically in colliers, differed in several important respects from the pulmonary abnormality found characteristically in hard-heading workers, which corresponded closely to the silicosis occurring in persons exposed to high concentrations of quartz. Finally, the pulmonary abnormality shown to occur in colliers was also found to some extent in coaltrimmers working at the docks.

While recognising the difference between the form of chronic pulmonary disease found in hard-heading workers and that found most typically in colliers, the Committee realised that the distinction would be impracticable in routine work, and they accordingly recommended that the comprehensive term "pneumokoniosis of coal workers" should be used in future to describe "all the pulmonary conditions described as due to dust in workers engaged in any operation underground in coalmines, in screens workers at collieries and in coaltrimmers at docks". Moreover, since dust-reticulation was clearly attributable to the industrial hazard and led to some degree of disability, it was recommended that the diagnostic criteria required for purposes of compensation should be widened in scope, so as to include not only the more fully developed lung changes but those established by the medical survey as comprising all the various stages of "pneumokoniosis of coal workers". The Council are glad to note that the Workmen's Compensation Act, 1943, gives power to make compensation schemes on the basis of these recommendations. Since the findings of the medical survey and pathological studies—together with the environmental researches described in detail in the present symposium—confirmed the opinion that the most important causative factor in the pneumokoniosis of coal workers was prolonged exposure to air-borne dust, the Committee in their first report made certain recommendations as to how exposure to such dust in coalmines might be lessened. In so far as further statutory powers are required to enable effect to be given to these recommendations, they also have been taken in the Workmen's Compensation Act, 1943.

The second report of the Committee on Industrial Pulmonary Disease deals with the environmental conditions in the mines which must be taken into

account in studying the causation of pneumokoniosis of coalminers. The term "environmental conditions" embraces the actual concentration of dust in the air breathed by the collier at the coalface, the nature of this dust and size of the dust particles, the composition and characteristics of the strata from which this dust is derived, the concentration in the air of irritant fumes derived from the explosives used in shot-firing, and the temperature and humidity of the air to which the miner is exposed during his work. Detailed reports on all of these factors in relation to the incidence of pneumokoniosis in the South Wales coalfield are given by the different investigators, and the Committee provide a covering report in which they are able to make certain recommendations with a view to diminishing the pneumokoniosis hazard. Some of these recommendations have already been made in the first report of the Committee.

In planning and carrying out the medical and environmental studies, the Committee and the investigators received much help from the Mines Department, and its officers, and a contribution to the cost of the work was made from the Miners' Welfare Fund. The Council gratefully acknowledge this co-operation, and, not less, that of the colliery owners, the trade union representatives, and the many coalminers and coaltrimmers concerned. They also wish to express their high appreciation of the services of the Committee and of all those who took part in the scientific studies. A list of the principal investigators is given on p. x.

19th April, 1943.

MEDICAL RESEARCH COUNCIL,
c/o London School of Hygiene and Tropical Medicine,
Keppel Street, London, W.C.1.

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CHRONIC PULMONARY DISEASE IN SOUTH WALES COALMINERS.—II. ENVIRONMENTAL STUDIES

A.—REPORT BY THE COMMITTEE ON INDUSTRIAL PULMONARY DISEASE

1. The First Report of the Committee (*Spec. Rep. Ser. Med. Res. Coun., Lond.*, No. 243, 1942) dealt with the results of the medical survey and pathological study of chronic pulmonary disease in South Wales coalminers. Simultaneously with the medical inquiries, investigations were made of the different environmental factors which may play a part in the causation of pneumokoniosis as this disease is encountered in the South Wales coalfield, and the detailed accounts of these investigations are presented in the following pages. In the first Report it was pointed out that air-borne dust must be regarded as the factor primarily responsible for the pneumokoniosis of coal-workers, and the present Report is mainly devoted to a consideration of the physical and chemical nature of the dust to which the miner is exposed while at the coalface, and to the chemical and petrological characteristics of the coalseams and immediately adjacent rock strata from which that dust is derived. In addition, more detailed information is given about certain factors which were regarded by the Committee in their first Report as possibly playing a contributory part in the development of pneumokoniosis.

A laborious technique is involved in the estimation of the concentration and size distribution of the dust particles in the air, as well as in the chemical and petrological analyses, and for this reason it has not been possible to study in detail the environmental conditions in all the mines included in the medical survey. With a selection of samples of coal and rock from different mines, it has been possible to gain a good general idea of the varying characteristics of the coal and rock strata in the coalfield as a whole, but there is one very serious difficulty that has to be faced when considering the influence on the miners of the air-borne dust at the coalface. Pneumokoniosis may take many years to develop, and the disease which is now unmistakable may have been started by conditions which prevailed ten, twenty, or more years ago. In the interval, the methods of mining and the ventilation of the pits may have altered substantially. At the beginning of the inquiry efforts were made to select mines for investigation in which conditions had not changed materially, but in spite of this precaution it was found that changes had, in fact, occurred in some mines. Thus, present conditions may differ from those existing during the greater part of the period in which men now suffering from pneumokoniosis were contracting their disability, and, in interpreting data relating to present-day conditions, changes in mining practice must be taken into account. To this difficulty in the interpretation of the observations made during the present inquiry, reference will be found in the reports of the different investigators. Another difficulty in interpretation is encountered in the bituminous and steam coal mines, since, in these, stone-dust is applied to the roadways with a view to limiting the propagation of coal dust explosions, and some of this dust may be carried to the coalface in the air current.

Summaries are given by the investigators at the end of each of their reports, and the Committee in this covering report propose only to deal briefly with the salient features.

2. Professor Briscoe and his colleagues have concluded from their investigation of samples of air-borne dust, collected on naphthalene filters at the coalface in twelve mines, that there is a significant association between the incidence

of pneumokoniosis and (a) the average mass concentration of the total air-borne dust and (b) the mass concentration of the ash obtained from this dust.

It is now generally agreed that silicosis caused by the inhalation of quartz dust is attributable to particles which are below 5 microns in size. It is therefore likely that in the causation of pneumokoniosis in coalmines the principal danger of air-borne dust at the coalface is to be found in particles of this size, which can penetrate to the depths of the lungs more readily than larger particles.

Dr. Bedford and Dr. Warner have examined in detail, with the aid of the thermal precipitator, the size distribution of the air-borne dust particles at the coalface, and have calculated the mass concentrations both of coal particles and of mineral matter other than coal, for different ranges of particle-size. The interpretation of these results is subject to the difficulty of changing environment to which attention has already been drawn. A careful review of the past history of the mines suggested that, at two of the high-incidence mines (one of which was of particular importance from the medical aspect, a full clinical and radiological examination of the entire colliery population having been made), the concentrations of air-borne dust in earlier years had been distinctly higher than those measured during their investigation; yet at one of these two mines, that with the highest incidence of pneumokoniosis observed in the medical survey, the average concentration of minerals other than coal, as measured, was the highest recorded by these investigators. In the bituminous mine studied, limestone dust (which is generally regarded in this country as harmless) was used for stone-dusting the roadways, and a certain amount of this—though what precise proportion it has been impossible to determine—is found in the air-borne dust to which the collier is exposed at the coalface. In spite of these complicating factors, there is evidence of an association between the incidence of pneumokoniosis and the calculated mass concentration of particles, particularly those below 5 microns in size, both of coal and of mineral matter other than coal.

In view of the difficulties mentioned, and of the fact that, owing to the laborious technique, only five mines could be examined by the thermal precipitator method, the Committee, whilst agreeing with the probability of the conclusion reached by Dr. Bedford and Dr. Warner, must point out that they are here dealing with a probability, not with a certainty. They feel that doubt might be dispelled if additional evidence could be secured by the extension of the investigations by means of the thermal precipitator to a larger number of mines.

3. Mr. Hicks and Dr. Nagelschmidt give the results of chemical and X-ray diffraction analyses of the mineral matter of the coal seams, the rock strata adjacent to the seams, the air-borne dusts at the coalface, and certain screened fractions of run-of-mine coal. Kaolin and carbonates predominate in the coal seam mineral matter, mica (illite) and quartz in the rock strata. The dusts and screened fractions are very similar to each other and show all these constituents.

The proportions of quartz in the rocks and air-borne dusts vary, but they show no clear relationship to rank of coal or pneumokoniosis incidence, except in the case of the anthracite mines, where the dusts, in general, have more quartz in high than in low incidence mines. On an average, the dusts from all mines (anthracite and non-anthracite) contain 2 per cent. of quartz and, in the absence of limestone used for stone dusting, the proportion of quartz in the ash increases with the ash percentage of the dust.

Certain differences related to the rank of coal are described, e.g., in passing from anthracite to bituminous coal the sodium content of the mica in the rock decreases, while in the mineral matter of the coal seam the kaolin changes from halloysite to kaolinite type and the total ash, and the proportions of kaolin and carbonates in that ash, increase. But the investigators draw attention to the apparent general similarity of the samples, and to the desirability of studying the coal material itself, as anthracite coal may, alone or in conjunction with the other components of the dusts, prove a greater hazard than bituminous coal.

The report by Dr. Brammall and Mr. Leech includes a detailed petrological description of the rock strata overlying the coal in different mines, together with supplementary analyses. There is a contrast between the shales in the anthracite and in the bituminous coal areas. This is attributable to differences in degree of compaction and metamorphism, and perhaps also of temperature—factors which appear to have determined coal grade, anthracite being associated with the higher pressure conditions. As a result, there is in the anthracite area an increase in the content of secondary quartz and mica and a differentiation in the ground-mass or ultimate cement substance in the shale. Hydrated ferric oxide and alumina, which depress the solubility of silica, are less evident in the ground-mass of the shales of the anthracite area than in that of the shales of the bituminous area. The incidence of pneumokoniosis seems to be associated, though not necessarily directly, with the geological changes caused by pressure.

4. Comparisons by Dr. Bedford and Dr. Warner of the dust concentrations during ripping and coal-getting lead to the conclusion that ripping dust should be eliminated as far as possible from the air breathed by the collier. Professor Briscoe and his colleagues show that the ash percentage of the air-borne dust during ripping operations is much higher than that during coal-getting, and Dr. Nagelschmidt's data show that higher quartz percentages are associated with such higher ash percentages. These findings strengthen the suggestions made by Dr. Bedford and Dr. Warner, and are in keeping with the recommendations made in the Committee's first Report, namely, that ripping and packing should be done, as far as possible, on a back-shift when the collier is away.

5. In the investigations described in this Report, the determination of the size distribution of the particles in the air-borne dust has been made with the thermal precipitator. While this instrument provides more complete and reliable information than can be obtained by other existing instruments, it is probably too elaborate for routine use when assessing the efficiency of methods of dust suppression; it might well, however, be adopted as the standard instrument for calibrating any instruments which are used for routine work. Mass samples of dust taken by filters are not adequate by themselves when pneumokoniosis is under consideration, for these give undue prominence to the larger particles, which are not so dangerous as those of smaller size. It is possible that the komimeter, which has been extensively used in the gold mines on the Rand, or the Owens' jet dust-counter, may serve for this purpose, but further study of these or other instruments under the conditions prevailing in the coalmines in South Wales is necessary before a decision can be reached.

In their report, Dr. Bedford and Dr. Warner suggest certain standards of permissible dustiness in the air breathed by the miner. While the standards suggested may serve as a target at which to aim for the present, the Committee feel that it would be a mistake to lay down any rigid standards until the results of further investigations on the lines already suggested are available, and additional information has been obtained about the extent to which the concentration of air-borne dust can be reduced by methods that are practicable at the coalface.

6. The thermal conditions prevailing throughout seven of the mines studied in the medical survey have been examined by Dr. Bedford and Dr. Warner. The incidence of pneumokoniosis appears to be influenced neither by the temperature at the coalface nor by the humidity of the air. The apparent inverse relationship of incidence to humidity and dampness found by the medical investigators is probably due to wetness of the surfaces of the strata diminishing dust concentrations. Figures are given which show the considerable chilling effect experienced when riding in a spake train up the slants from the workings to the surface, but, although there may be some degree of association between that chilling and the incidence of pneumokoniosis, it seems clear that spake-riding can at most be but a contributory factor, i.e., of secondary rather than primary importance—a conclusion which is in agreement with the medical evidence discussed in the first Report of the Committee.

7. The work of Mr. Ivon Graham and Dr. Runnicles shows that the average concentration of nitrous fumes liberated during shot-firing rarely exceeds 6 parts per million by volume in air samples taken during the period of a shift, or 4 parts per million over a whole 24-hour period. There seems to be no direct association between the concentration of nitrous fumes and the incidence of pneumokoniosis, but it would be imprudent as yet to disregard the slightly irritant effect of low concentrations of these fumes as a possible contributory factor in the causation of the disease. Just after shot-firing, higher peak concentrations were observed, but these last only for a brief period, since the explosion fumes are diluted and swept away by the air current at the coalface. Means for reducing the concentration of nitrous fumes are discussed by the authors. Relegation of shot-firing to a back-shift would diminish any possible deleterious effect of nitrous fumes and at the same time reduce the risk of exposure to the exceptionally high concentration of dust which is an immediate result of the firing of a shot; this procedure, where practicable, has been recommended in the first Report of the Committee.

In this Report, the concentration of nitrous fumes is expressed in terms of nitrogen dioxide. Further information is desirable about the relative amounts of nitric oxide and nitrogen dioxide in the fumes, since there is some evidence that the two oxides differ in toxicity.

8. The environmental conditions in the mines are described in detail in the different reports. In view of the complexity of the problem, the Committee do not feel justified at this stage in drawing final conclusions in regard to the causation of pneumokoniosis or to the differences in incidence observed in the South Wales coalfield. With the evidence that the air-borne dust inhaled by the miner is the primary cause of pneumokoniosis, the problem has to be faced that dust in the anthracite mines is more dangerous than that in the bituminous mines. The problem is not limited to South Wales, for it has been shown in the medical report that a similar state of affairs obtains in the coalmines of both the U.S.A. and the U.S.S.R. It may be that it is a question of the concentration of the air-borne dust only, or the character of the dust may be the determining factor. The present Report suggests that both factors may be involved. In ordinary silicosis, quartz is considered to be the main hazard, and in reports from the U.S.A. the same conclusion is reached for what we have now termed pneumokoniosis of coal workers. The present data regarding dust composition give little positive support to this view so far as the South Wales coalmines are concerned, but as there is a correlation of the concentration of dust and of dust ash with the incidence of pneumokoniosis, it is not possible to exclude the quartz theory. It should, however, be remembered that the pathological features of the pneumokoniosis of coalworkers differ from those of ordinary

silicosis, and this may be due to the interaction of the various other constituents in the dusts with the quartz. Thus, the differences in the chemical and petrological nature of the dusts and their sources, as well as the differences in dust concentration, may account for the variations in pneumokoniosis incidence described in the first Report. The significance of these differences can probably be decided only by experimental trial on animals, of the different constituents of the dusts taken both singly and in various combinations. Some experiments of this nature have been made under the Committee's direction, and the results will form the subject of a further publication.

But whatever may be the ultimate reason for the greater danger of the dust in the anthracite than in the bituminous mines, the Committee wish to emphasise again the fact that a reduction in the amount of air-borne dust breathed by the miner in the course of his work is the one immediate measure which is likely to diminish the incidence of pneumokoniosis. Dr. Bedford and Dr. Warner give some figures to show the remarkable reduction in the dust concentration at the coalface which can be achieved by wetting the coal or the rock debris, by means of a simple water spray, before shovelling it. The use of water sprays and mists for dust prevention or suppression is well known to mining engineers, and striking results have been obtained recently by watering at the coalface in certain bituminous mines in the U.S.A. and in association with the coal-cutting machine in a steam-coal colliery in South Wales. The Committee have learnt with satisfaction that the Amalgamated Anthracite Collieries have established a research committee which is actively investigating the dust problem in the mines under their control, and which has initiated experimental trials of methods by which water can be used as an aid to dust suppression at the coalface.

9. The recommendations made in the first Report were based in part on the medical survey and in part on the information then becoming available to the Committee from the environmental studies, the complete results of which are given in this symposium. Now that the accounts of these studies are available, the Committee wish to make the following recommendations in view of the importance of reducing the pneumokoniosis hazard. Some of these recommendations have already been made in their first Report.

- (1) Every effort should be made to maintain an adequate volume of ventilation at the coalface, so that the dust in the air breathed by the men may be kept at as low a level as possible.
- (2) The systematic use of water as an aid to dust suppression at the coalface itself should be fully tested, particular attention being given to the wetting of dry coal and rock debris before they are moved.
- (3) Mist projectors or other methods should be used to allay the dust in mine roadways and at loading points.
- (4) Shot-firing, whether in stone or in coal, should be reduced to a minimum and, as far as practicable, carried out when fewest men are likely to be exposed to the dust and fumes arising therefrom.
- (5) All the processes of ripping, including the disposal of rippings, should, where practicable, be carried out on a back-shift.
- (6) Suitable means to prevent chill should be used during spake journeys.

The Committee wish to record their appreciation of the work done by the different investigators, and of the scientific ability with which they have faced a very laborious task. They again wish to express their gratitude to the mining industry in South Wales, and to the officials of the Mines Department, for their ready co-operation and assistance.

CHRONIC PULMONARY DISEASE IN SOUTH WALES COALMINERS

LIST OF PRINCIPAL MEDICAL AND SCIENTIFIC INVESTIGATORS CONCERNED IN THIS INQUIRY

(*Note.*—The whole scheme of research has been directed by the Committee on Industrial Pulmonary Diseases, appointed by the Medical Research Council. A list of this Committee has been given on p. ii.)

MEDICAL SURVEY*

- P. D'ARCY HART, M.D., F.R.C.P.—*Member of Scientific Staff, Medical Research Council.*
E. A. ASLETT, M.R.C.S., L.R.C.P., D.P.H.—*Tuberculosis Physician, Welsh National Memorial Association.*

PATHOLOGICAL STUDIES*

- T. H. BELT, M.D. (Tor.), B.Sc., M.C.P.S. (Ont.). *Reader in Pathology, British Postgraduate Medical School, London.*
A. A. FERRIS, M.B., B.S. (Mel.).—*British Postgraduate Medical School, London.*
E. J. KING, Ph.D.—*Reader in Biochemistry, British Postgraduate Medical School, London.*
G. NAGELSCHMIDT, D.Phil.—*Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts.*
A. F. S. SLADDEN, M.D.—*Pathologist, Swansea General and Eye Hospital.*

ENVIRONMENTAL STUDIES

- T. BEDFORD, D.Sc., Ph.D., M.I.Min.E.; C. G. WARNER, Ph.D., B.Sc.—*Members of Staff, Industrial Health Research Board, Medical Research Council.*
A. BRAMMALL, D.Sc., Ph.D., F.I.C., D.I.C., F.G.S.—*Assistant Professor of Geology, Imperial College of Science, London.*
Major J. G. C. LEECH, A.R.S.M., D.I.C., F.G.S.—*Department of Geology, Imperial College of Science, London.*
Professor H. V. A. BRISCOE, A.R.C.S., D.Sc., D.I.C., F.I.C.; P. F. HOLT, Ph.D., D.I.C., F.I.C.; N. SPOOR, A.R.C.S., Ph.D., D.I.C., A.I.C.; JANET W. MATTHEWS, Ph.D., D.I.C., F.I.C.; PHYLLIS M. SANDERSON, Ph.D., D.I.C.—*Department of Inorganic and Physical Chemistry, Imperial College of Science, London.*
J. IVON GRAHAM, M.A., M.Sc., F.I.C., F.R.C.Sc.I.—*Director, Mining Research Laboratory, British Colliery Owners Research Association, Royal School of Mines, London.*
D. F. RUNNICLES, Ph.D., A.I.C.—*Mining Research Laboratory, British Colliery Owners Research Association, Royal School of Mines, London.*
D. HICKS, M.Sc., A.I.C.—*Officer-in-Charge, Coal Survey Laboratory (Department of Scientific and Industrial Research), Cardiff; and Laboratory Staff.*
G. NAGELSCHMIDT, D.Phil.—*Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts.*
J. THEWLIS, M.Sc.—*National Physical Laboratory, Teddington, Middlesex.*
Major R. YATES, D.S.O., M.C.—*H.M. Divisional Inspector of Mines.*

* See *Spec. Rep. Ser. Med. Res. Coun., Lond., No. 243, 1942.*

CHRONIC PULMONARY DISEASE IN SOUTH WALES COALMINERS.—II. ENVIRONMENTAL STUDIES

B.—PHYSICAL STUDIES OF THE DUST HAZARD AND OF THE THERMAL ENVIRONMENT IN CERTAIN COALMINES

BY

T. BEDFORD, D.Sc., Ph.D., M.I.Min.E.,

AND

C. G. WARNER, Ph.D., B.Sc.

(Members of Staff, Industrial Health Research Board)

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PART I—GENERAL

INTRODUCTION

One of the aims of the investigation of chronic pulmonary disease amongst anthracite miners in the South Wales coalfield has been to search for occupational conditions which may be related to the occurrence of the respiratory disease. Among the environmental factors to which attention has been directed are (i) the dust to which the workers in various mines are exposed, and (ii) the temperature and humidity of the workplaces; for, in the investigation of any pulmonary disease associated with dusty conditions, a study of the dust concentrations is clearly indicated, and where, as in coalmines, the workers may be exposed to substantial variations of temperature, the possibility that the disease may be influenced by temperature conditions cannot be ignored. Accordingly, various studies of dust have been carried out, and surveys have been made of the temperature and other thermal conditions in a number of mines.

It has not been found practicable to make thorough surveys of the working conditions at all the collieries at which the miners examined by the medical investigators were employed, and the observations have therefore been limited to certain selected mines. It was obviously desirable that surveys should be made at mines where the incidence of pulmonary abnormalities was high and at others where the incidence was low, and that an attempt should be made to explain the difference in incidence at different mines within the anthracite area. The choice of mines was therefore based on the findings of the medical investigators, and, for the dust surveys, four anthracite mines, A.1, A.2, A.3 and A.8, and one bituminous mine, B.3, were selected. Temperature surveys were made at each of these five mines and at two other anthracite mines, A.4 and A.7.

In coalmines the risk of incurring pulmonary disease is undoubtedly greatest amongst hard heading workers, but relatively few persons are engaged in that type of work, and consequently the number of cases of pulmonary disease amongst such workers is not large. From the point of view of the industry, the incidence of pulmonary abnormalities amongst the miners at the coalface is a much more serious problem, since many more cases of pulmonary abnormality occur amongst them than amongst other underground workers. The environmental investigations here described have, therefore, been made with the object of securing data for correlation with the incidence of pulmonary abnormalities amongst coalface workers. Thus, except for some observations made in the roadways at Colliery A.3, the dust sampling was confined to the coalface. On the other hand, the observations of thermal conditions have not been confined to the coalface but have been made throughout each colliery, for although during the greater part of the shift the miner is exposed to fairly stable temperature conditions at the coalface, he is often subjected to substantial changes of temperature and wind velocity during the journey between the coalface and the surface.

In their medical survey, Hart and Aslett (*Spec. Rep. Ser. Med. Res. Coun., Lond.*, No. 243, 1942), have ranked the collieries included in their investigation according to the incidence of pulmonary X-ray abnormalities amongst the colliers, and as a measure of the relative incidence at any colliery they have expressed the observed number of X-ray abnormalities classed under the heading

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"consolidation" at that colliery as a percentage of the "expected" number.* Below, the seven collieries examined by us are shown in order of diminishing incidence:—

<i>Colliery.</i>	<i>Observed incidence of X-ray abnormalities ("consolidations") amongst coalface workers, as percentage of expected value.</i>	<i>Broad classification of incidence.</i>
A.1	233	High
A.3	172	High
A.8	146	Medium
A.7	95	Medium
A.4	55	Low-medium
A.2	12	Low
B.3	4	Low

CHANGES IN WORKING CONDITIONS

A serious difficulty attending the investigation of chronic pulmonary disease in industry is that of obtaining a satisfactory measure of the health hazards to which the workers have been exposed. Industrial methods are not static, and changes in lay-out or in methods of work frequently result in changes in occupational risk. Thus, in coal mines it is a simple though laborious task to make an adequate survey of present-day working conditions, and such surveys have been made in this inquiry. But it does not follow that the thermal conditions and the dust concentrations measured in the last two or three years truly indicate the conditions that have prevailed for a period of perhaps twenty years or more, during which the miners now suffering from pulmonary abnormalities have been contracting their disability. In selecting mines for the medical survey, which preceded the environmental studies, an attempt was made to choose those at which, so far as could be ascertained, no serious changes in mining practice has occurred which would be likely to invalidate comparisons between the collieries. In spite of this care, however, it appears that at two of the collieries the conditions measured do not strictly represent those which prevailed in former days, and when later the thermal and dust measurements are related to the medical findings this fact must be kept in mind.

Below are given some brief notes on the collieries included in this inquiry.

THE COLLIERIES INVESTIGATED

(a) *Colliery A.1.*—As at the other anthracite collieries dealt with in this report, access to this mine is by a slant from the surface. The only seam now worked is the Lower Pumpquart, and this is worked on the advancing longwall system. In 1927, mechanical conveyors were first introduced, and at the time of our investigation 75 per cent. of the output of the colliery was obtained from conveyor faces: the remaining coal was got from longwall stalls. Despite the use of conveyors, the coal is not intensively mined, and the conveyor faces

* The method of obtaining this percentage for a given mine was as follows. The percentage-incidence of "consolidation" was first calculated for the eight anthracite mines included in the medical study, taken as one group, for men of under 10, 10-20 and 20 or more years of employment as collier. These three rates were then applied to the total numbers of men of each length of employment who were examined at the given mine. The results show how many men at this mine would have been expected to have "consolidation" if the mine in question had had the same incidence-rates as the whole anthracite group. The number actually observed with "consolidation" at the mine, expressed as a percentage of this calculated expectation, shows its position relative to the other collieries similarly treated. In other words, the anthracite group has been used as a standard against which to weigh the experiences of each separate mine, anthracite or non-anthracite.

advance but little faster than the stall faces. Since 1933 all shotfiring has normally taken place in the afternoon or night shifts, when very few men are at work.

Observations of the temperature and other thermal conditions were made throughout the colliery, and the average results obtained probably give a good indication of the conditions at this colliery for many years past.

Since, in earlier years, the whole or the bulk of the output was obtained from longwall stalls, it was desirable that the dust survey should be made in such places, and not on the now more common conveyor faces. The stall districts which were typical of earlier working conditions were almost worked out when it was desired to make the dust survey; and, in order to reproduce as nearly as possible the earlier conditions, the management generously arranged to open up a short length of face about 1,400 yards down the slant, representing the position of the working face some 15 or 20 years ago. This was worked in stalls and the ventilation was restricted, in an attempt to simulate the former conditions: it was along this coalface that the dust observations to be described later were made. Arrangements were made for shots to be fired on this face during the day shift. Owing to the need to remove gas, the ventilation could not safely be restricted enough to reproduce the former conditions, and the air flow was distinctly better than would have been found in a more remote district some years earlier. Partly because of this better ventilation, and partly because of the small number of working places, there can be no doubt that the dust concentrations measured on this coalface were substantially lower than those which generally prevailed in longwall stalls at the same colliery several years ago.

(b) *Colliery A.2.*—Roughly 90 per cent. of the output of this colliery is obtained from the Lower Pumpquart Seam, and the environmental surveys were confined to this seam. The seam is worked on hand-cut longwall faces, with topholes on the steeper gradients and stalls on the flatter ones. The men employed in topholes fill tubs at the loading ends, where the dust concentrations are higher than at the coalface. To reach the loading ends, they scramble down the topholes, disturbing much dust as they go. There is much blasting, and shots are fired on the day shift as required.

Owing to some increase in the depth of working, and consequently increased dryness, the amount of dust produced here has probably increased somewhat in recent years, but this increased dust production has been offset by improved ventilation at the coalface. The net result of these changes is that the dust concentrations of to-day probably give a good representation of the dust hazards for many years past. It is probable, too, that the average thermal conditions have been very stable.

(c) *Colliery A.3.*—By far the greater part of the output from this colliery is now obtained from the Stanlyd Seam. One other seam was being worked to a very small extent at the time of the investigation, but the output from it has never been considerable, and the observations were therefore confined to the Stanlyd Seam. When this seam was opened in 1924, it was worked in single stalls, on the pillar and stall principle (narrow working). In 1926 modifications were introduced by working skips and double stalls, and later advancing longwall working was begun. The double stalls have always been few in number. From 1928 to 1933 the number of longwall stalls was roughly equal to that of places worked as narrow or as double stalls. After 1933 the longwall stalls increased in number until, at the time of the investigation, they comprised roughly 90 per cent. of the working places; but during the period 1934 to 1940 single and double stalls together still accounted on the average for 18 per cent. of the total working places. The transition from narrow to longwall working has undoubtedly been accompanied by a great reduction in the dust hazard, for longwall faces are commonly better ventilated than narrow places, and

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consequently there is a greater flow of air to dilute the dust produced by mining operations.

Another factor which has contributed to the reduction of dust concentrations in recent years is the improvement that has been made in the general ventilation of the colliery. In 1936 a second main air intake was brought into use, and this increased the volume of air circulating in the mine. Since about that time the more remote districts have been closed and work has been concentrated on a few well-maintained longwall faces, and this has resulted in a much better utilization of the air available for ventilation. It follows that the dust measurements recently made on the longwall faces at this colliery can give no indication of the dust concentrations which prevailed in the Stanlyd Seam a number of years ago, when ventilation was poor and narrow places relatively numerous. Observations were made in a few isolated narrow places, but even these were better ventilated than the similar places of former years, and since at the time of our observations the narrow places occurred only singly, the dust concentrations encountered were certainly lower than would have been found in a district with a number of such places on a single air circuit. During our observations the air entered a narrow place relatively clean, and was fouled only by dust in that one place; but in earlier years the air passed from narrow place to narrow place and became progressively more heavily laden with dust. Up to the opening of the Stanlyd Seam in 1924 longwall working has been the practice, but the ventilation in those days was admittedly poor, and high dust concentrations must undoubtedly have been common.

The improved ventilation has certainly resulted in an increased rate of air movement at the coalface, but apart from that difference the average thermal conditions observed by us are probably fairly representative of the average conditions at the colliery for many years past.

At this colliery shots are fired on the day shift as required.

(d) *Colliery A.8.*—The principal seams worked at this colliery are the Nine Feet and the Yard Seams. The Yard Seam is now mainly worked intensively: conveyors have been used there since 1923, and nearly all the coal has been undercut by machine since 1927. Until quite recently the Nine Feet Seam was worked by a form of the pillar and stall system, the coal being got by hand, but the "Barry" longwall system has now been introduced in most of the seam. At the time of the investigation one portion of the seam was still worked by pillar and stall, and the dust sampling was confined to this area. On account of the changes in method of working in the Yard Seam, it was thought inadvisable to take samples there. No shots are fired in either the roof or the coal of the Nine Feet Seam. Surveys of the thermal conditions were made in both seams.

The installation of a new fan in 1934, and the duplication of air intakes and returns, have increased the volume of air circulating in this colliery. The increased air-flow, however, is largely counterbalanced by more extensive workings at greater distances from the surface, and, in the opinion of the colliery executives, the ventilation at the coalface is much the same now as it has been for several years past. It appears that for this colliery the data obtained in the surveys give a reasonably accurate measure of the working conditions of earlier years.

(e) *Colliery B.3.*—This is the only bituminous coal mine, and the only mine with shafts, included in our survey. The two main seams here are the Black and Meadow Veins. Observations were made in both. There is no shot firing in either seam. Since the coal mined is bituminous, routine stone-dusting of the roadways must be carried out, and limestone dust has been used for this purpose for about ten years past. There seems no doubt that the observed conditions give a good indication of the working conditions for many years in this mine.

(f) *Colliery A.4.*—The four seams now being worked at this colliery are the Rock Vein, the Little Vein and the Upper Pumpquart and Stanlyd Seams. Each of the seams is worked on the advancing longwall system. In the three upper seams gravity conveyors have been used since 1930, but the Stanlyd Seam is still worked in stalls. All the coal is hand got.

The completion of a cross-measure drivage in 1935 effected an improvement of ventilation, but the only sensible change in the thermal conditions is likely to have been some increase in the air velocity. The colliery is comparatively shallow, and it is unlikely that the temperatures at the coalface were appreciably affected. The average thermal conditions observed can therefore probably be taken as reasonably representative of earlier conditions.

This colliery has been described as a "dry" one. In none of the seams was any quantity of water noticed on the floor, but in the two shallower seams, especially in the uppermost—the Rock Vein—the roof and the coalface were distinctly moist.

(g) *Colliery A.7.*—Three seams, the Eighteen Feet, the Nine Feet and the Yard, are worked at this colliery. The Eighteen Feet Seam is worked on the pillar and stall system, and the Nine Feet Seam was worked by that method until 1935, when longwall working was introduced. The Yard Seam has always been worked on the longwall system. In 1935 and 1937 improvements were made in the ventilating arrangements, but, as at Colliery A.8, these improvements have been offset by more extensive workings at greater distances from the surface. It seems, therefore, that for many years the thermal conditions have been approximately those indicated by the results of our temperature survey.

PART II—A PHYSICAL STUDY OF THE DUST HAZARD IN CERTAIN MINES

INTRODUCTION

In aetiological studies of industrial pulmonary disease the fullest possible information about the dust breathed by the workers is desirable. It is necessary to know not only the chemical and mineralogical nature of the dust, but also its concentration and other physical characteristics. These characteristics include (i) the mass concentration—*i.e.*, the mass of dust in unit volume of the dust cloud; (ii) the number of particles per unit volume; (iii) the size distribution of the particles; and (iv) depending upon (ii) and (iii), the surface area of the dust particles contained in unit volume of the cloud.

Studies of the mineralogical nature of the dust, and of its chemical composition, are described by other contributors to this symposium. In this report we are concerned with the physical estimation of the dust hazard; but we have taken the mineralogical nature of the dust into account to some extent, for we have been able to describe separately (a) the coal itself, and (b) the other particles present in the air of the mines examined.

The primary object of the study was to survey the dustiness of various mines so that the data thus obtained could be correlated with the results of the medical survey, but interesting information concerning the influence of certain factors on dust concentrations has also been obtained.

Dust-sampling instruments vary considerably in their efficiency, and the different techniques employed to evaluate dust samples also influence the results obtained. In order that a comparison can be made between the dust measurements obtained in this study and those previously made in other investigations, some discussion of dust-sampling methods, and of measurements of dust concentrations, is necessary; and in the interest of clarity this discussion will be given before the results obtained in the field survey are described.

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COLLECTION AND EVALUATION OF DUST SAMPLES

1. Sampling methods

The physical bases of the many dust-sampling instruments which have been used in the past half-century include settlement, filtration, washing, impingement, electrical precipitation, and thermal precipitation. It is unnecessary here to give a full catalogue of the many sampling instruments that have been used. For a review of the earlier methods reference should be made to Cunningham (1873) and Heyman (1931). Here it is enough to mention a few of the principal methods of to-day, and below brief descriptions are given of the konimeter, the impinger, the jet dust counter, the thermal precipitator, and the naphthalene filter.

(a) *The konimeter*

The konimeter was developed 25 years ago by Sir Robert Kotzé, for use in the gold mines of the Witwatersrand. It is in the form of a small valveless suction pump with a spring-operated piston. The piston is depressed and held by a catch, and when it is released a volume of 2.5 or 5 c.c. of air is sucked in and made to impinge at high velocity on a glass plate previously rendered sticky by being smeared with vaseline or with a special glycerin jelly. Thus the dust contained in the air sample is made to adhere to the plate. There are two forms of konimeter, one in which the sample is taken on a rectangular glass slide, and the other in which a circular glass plate is used. With the circular plate thirty numbered samples can be taken on the same glass disc.

The South African method of evaluating konimeter samples is described by Boyd (1930). A microscope with a 16 mm. objective and a high-power eyepiece is used. In the eyepiece a micrometer ruled in sectors of 9° or 18° is inserted, and the particles in two or more sectors are counted. At first the counting was done by ordinary transmitted light, but it was soon found that the numerous fine particles could not thus be counted, and a modified method of dark-ground illumination was evolved. A dark-ground stop of 10 mm. diameter is placed immediately below the condenser. This cuts out the central portion of the pencil of light and allows the particles to stand out clearly, so that they are easily countable. For illumination a 100 c.p. $\frac{1}{4}$ -watt, ground-glass bulb is placed about 9 inches from the mirror.

In making particle counts complication was found to arise from the presence of minute salt crystals and particles of soot. These are now removed before counting. The samples are collected on slides of heat-resisting glass; the slides are treated with hydrochloric acid and then washed by repeated immersion in distilled water to remove acid-soluble particles, and they are afterwards heated to redness to remove organic particles. On slides so treated the silica particles show up distinctly.

For the evaluation of their konimeter samples the U.S. Bureau of Mines use a microscope with a 16 mm. ($\times 10$) objective and a compensated $\times 20$ eyepiece, giving an overall magnification of 200. Counting is done with light-field illumination. With this technique particles much below one micron* in size cannot be resolved.

(b) *The impinger*

In the Greenburg-Smith impinger, now used as the standard instrument for dust sampling in the United States, the principles of impingement and water washing are both employed. The apparatus consists essentially of two portions: first, a source of suction sufficient to draw the air to be sampled through the sampling device; and, secondly, the sampling device itself. This latter consists of a container and the impinger tube and plate. Various suction arrangements have been contrived, utilising either electrical or compressed

* A micron (μ) is one-thousandth of a millimetre, or approximately one twenty-five-thousandth part of an inch.

air apparatus, and a hand-driven apparatus has been devised by the U.S. Bureau of Mines. In sampling, the air is drawn through the impinger tube and made to impinge at high velocity on the glass plate immersed in a liquid, usually water. The dust from the air is precipitated on the plate and retained in the liquid. Counts are afterwards made of the particles in a fraction of the collecting liquid.

The microscope used for counting has a $\times 10$ (16 mm.) objective, and light field illumination is employed. Dark-field counts are frequently also made, so that, by comparison with the light-field counts, an idea of the proportion of fine particles can be obtained (Hatch and Pool, 1934). The exact sizes of the smallest particles revealed by the light- and dark-field techniques are not known, but a rough estimate for the light-field method is 1 micron, and for the dark-field about 0.2 micron (Brown and Schrenk, 1938).

By evaporating a portion of the sample to dryness a gravimetric estimation of the dust concentration can be made, but the method does not appear to be entirely free from trouble.

(c) *The jet dust counter*

The Owens jet dust counter is another instrument of the impingement type, It consists of an entrance chamber and an arrangement by which the air in that chamber is projected, by means of a hand pump, against a microscope cover slip. The nozzle velocity is of the order of 200 metres per second, and, since the entrance chamber is lined with moistened blotting paper, the great pressure drop which occurs brings about supersaturation of the air. Condensation takes place, and the moisture helps the dust particles to adhere to the surface of the cover slip. The moisture evaporates, but the dust particles remain securely fixed.

The dust samples are subsequently mounted on slides and examined under the high-power microscope. Particle counts are made and the size distribution of the particles can be ascertained.

(d) *The thermal precipitator*

In the thermal precipitator, developed by Green and Watson (1935), an aspirator draws the air to be sampled vertically downwards through a slot and past a horizontal, electrically heated wire, on either side of which are circular cover slips. As the air passes slowly by the heated wire, the dust particles are thermally repelled from the wire and precipitated on the cover slips. The slips are then mounted on slides for microscopic examination.

The records are counted in the same way as those of the jet dust counter. A 2 mm. oil-immersion objective is used with a $\times 15$ to $\times 20$ eyepiece. Particle counts and size distributions are readily measured in this way.

The dust samples described in this report have been obtained by means of this instrument.

(e) *The naphthalene filter*

The dust-sampling methods already referred to are all primarily intended for the measurement of numerical concentrations. For gravimetric estimations, many kinds of filter have been used. Professor H. V. A. Briscoe and his colleagues (p. 79) have made large numbers of gravimetric observations, for which they have employed naphthalene filters. The apparatus will be described by them, and here it is enough to say that the air to be sampled is drawn through a bed of naphthalene and the dust thus trapped. Later, the naphthalene is sublimed and the dust remains to be weighed and its ash content determined.

2. Comparison of dust-counting methods

Green and Watson (1935) made critical comparative tests of a number of dust sampling methods, and discussed the advantages and disadvantages of

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the different instruments. The following remarks are based on their conclusions:—

(a) *The konimeter*

The advantages of this instrument are that it can be used for taking a snap sample of the dust; it is portable and readily manipulated even in positions that are not easily accessible; the sample can be examined at the place of sampling if a suitable microscope is attached to the instrument, and a number of samples can be taken on one glass disc. There are several disadvantages. Only a very small sample of air can be sampled, and this may not truly represent the average air at the time of sampling. Since the dust concentration may vary rapidly with time, a large number of samples must be taken before an idea of the average dustiness, even for a short period, is gained. The collecting efficiency of the instrument is low except for low dust concentrations containing no really large particles. Owing to the difficulty of obtaining a uniform film on the glass plate, samples lack uniformity and the probable error of a single observation is high. It is difficult to determine the size frequency of the dust. The particles in the dust spots are usually aggregated and difficult to count. Under dark-ground illumination, except when the number of particles is low, counting is difficult and inaccurate, owing to the scattering of light from aggregates and from the surfaces of large particles.

(b) *The impinger*

The impinger possesses the advantages that the dust from a large volume of air can be collected, since the sampling rate is high; samples can be obtained for a lengthy period, sometimes up to 30 minutes; if first evaporated to dryness the samples can be subjected to quantitative analysis and petrological examination; low and high concentrations can be readily determined.

One of the chief drawbacks to the method is that the smallest particles detectable with the standard light-field technique are of the order of 0·8 micron. If the counting technique were altered to permit particles as small as 0·2 micron to be observed, shattering of the large particles by impingement and inefficient collection of the finer particles would affect the accuracy of the results. Samples can be preserved only a short time and must be analysed without delay, while soluble dusts cannot be estimated by the method. The accuracy of sampling may be influenced by the high rate of flow through the apparatus, and a further disadvantage is that it is difficult to make size frequency determinations.

(c) *The jet dust counter*

This instrument is essentially meant for the taking of snap samples and cannot be used for continuous long-period sampling. It is portable and easily manipulated, and the samples obtained can be examined under the high-power microscope. It is reasonably efficient for the collection of the finer particles, but it is inefficient for the larger particles which may yet be of pathogenic importance; it thus gives an inaccurate idea of the total particle count. Because of this differential efficiency, it gives an erroneous idea of the size frequency of the sample. Aggregation in deposits from clouds of high concentration may cause additional errors in counting.

(d) *The thermal precipitator*

Comparison of dust counts of thermal precipitator records with those yielded by the ultramicroscope and sedimentation cells confirms that the thermal precipitator is highly efficient. It appears that, for practical purposes, all particles likely to be of pathogenic importance are precipitated. The size distribution of the particles is similar to that given by the sedimentation cell up to a limit of at least 20 microns. The results of many hundreds of tests indicate that for ordinary work the probable error of observation is about ± 5 per cent.

(e) *Discussion*

It will be clear from the foregoing paragraphs that the particle count obtained for a particular dust cloud depends to a great extent on the method

of collection of the dust sample and on the microscope technique employed to evaluate it. Different methods give very different results. It seems that, of the four methods described, the thermal precipitator is that which gives the most accurate and complete information about the physical characteristics of the dust cloud, and it would appear that the thermal precipitator is the most suitable instrument for use in a study such as the present, where the fullest information about the dust is desired.

Although the other instruments mentioned give less accurate information, they are nevertheless of great value in dust control work, and indeed they have shown their worth in earlier researches. The systematic use of the konimeter in the South African mines has had much to do with the control of the silicosis hazard there, and in the hands of American workers the impinger has justified itself in the control of the pneumokonioses.

While in fundamental research one needs as accurate measurements as possible, in routine control work less precise measurements may give all the accuracy that is needed. Thus, in defence of the present impinger technique, Drinker (1940) remarks that although the impinger counts ignore most of the particles smaller than 1 micron, the fact remains that the counts correlate fairly well with the incidence of silicosis. He comments that dust counting as it is done today is not a measure of how much dust there is in the air; its purpose is to estimate the silicosis risk. Bloomfield (discussion on paper by Barnes, 1936) has said that experience with the impinger over many years has proved that the counts yielded by that instrument are highly correlated with the degree of silicosis and tuberculosis among the workers exposed to dust in various industries.

3. The significance of dust measurements

It has been mentioned that estimates of the concentrations of air-borne dust are sometimes expressed in terms of the mass concentration of the dust, and sometimes in terms of the number of particles in unit volume of the dust cloud. The total quantity of dust present in the air is most accurately expressed by the mass concentration, but this measure of dustiness is not necessarily the best index of the hazard to health. The size distribution of the dust particles is a matter of great hygienic importance. As a solid material is disintegrated into smaller and yet smaller particles, the surface area of a given mass of the solid is much increased, and, as a direct result, those properties which depend upon the activity of the surface molecules are greatly enhanced. Chemical and physical activity are both increased by fine division. Very large dust particles are probably of little pathological significance, but if present they have a great effect on the mass concentration. Largely on this account, in studies of the pneumokonioses, dust concentrations are commonly expressed in terms of the particle count. It has been said that, in the case of fibrosis-producing dusts, the particle count offers the best index of the danger of a dusty operation (Bloomfield and Dalla Valle, 1935).

In the present report dust concentrations are given both as mass concentrations and as particle counts, and before the field results are described some discussion of the significance of the two methods of assessment is desirable.

(a) *Pathological significance of particle size*

There is general agreement that small particles are more injurious than large, but as to the maximum particle size which can be considered to be of pathogenic importance there is some difference of opinion. Gardner and Cummings (1933) injected two groups of rabbits intravenously with equal masses of silica. The silica used on the first group consisted of particles of 1 to 3 microns diameter, and that used for the second group of larger particles, 6 to 12 microns in size. The fine particles caused changes in the liver, resulting in a typical hyaline, nodular, silicotic fibrosis; while the coarse particles were much less irritating

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and excited only a simple foreign body reaction which had progressed very little in three years. Another group of rabbits was injected with aluminium oxide particles, 1 to 3 microns in size. These particles were merely phagocytosed and produced no fibrosis where they were deposited. These observations, it was concluded, support the view that the injury produced by silica is specific and chemical, rather than physical in character.

It would appear that the greater injury caused by the more finely divided silica in the experiments of Gardner and Cummings could have been due to the greater surface area subtended by the finer dust used in their experiments, for equal masses of the two types of dust were injected. Some further evidence, however, appears to suggest that the injurious properties of a given type of dust do not depend only on the surface area, for Gardner (1939) has said: "We have injected a series of doses of silica particles of different sizes having comparable surface areas. Regardless of the total surface area the silica-significant reaction only occurs when the particles are 3 microns or less in diameter."

It is fairly generally accepted by American workers that, in estimating a dust hazard, particles larger than about 3 microns can be ignored. Sayers and Jones (1938) mention that the majority of particles found in the lung are 1 to 3 microns in size. We have examined the dust present in the nodules in the lungs of a silicotic anthracite miner and have found that less than 40 per cent. of the particles visible under the high-power microscope were between 1 and 3 microns in size, while more than 50 per cent. were smaller than 1 micron. Gardner (1939) remarks that particles as large as 10 microns are found in human lungs, and Dr. E. L. Middleton informs us (personal communication) that he has observed particles even as great as 40 microns in the lungs. In our own very limited observations on lung sections the largest particles observed in nodules were 8 microns in diameter.

Belt and Ferris (*Spec. Rep. Ser. Med. Res. Coun., Lond.*, No. 243, 1942) have remarked that the collier's lung is in a very real sense his occupational log book; and, in fact, the size frequency of the dust particles in the lung sections examined by us was not unlike the average size distribution of the dust in the air of anthracite mines. Relatively few particles larger than 3 microns were observed in the lungs, and relatively few particles above that size are actually present in the air breathed by the miner during life. It may be that while particles as large as 40 or even 50 microns can enter the lung they are relatively inert and do not contribute to the causation of fibrosis, whereas, as has been said, particles of 8 or 10 microns diameter are actually to be found in silicotic nodules and must presumably be of some pathological significance.

It would be hazardous to assume that particles below about 1 micron in size are of no significance. Irvine (1940) says that the experimental evidence is all in favour of the conclusion that down to an undefined limit the finer the dust the greater the reaction, and Drinker (1939) remarks that the most dangerous sizes of silica particles are certainly below 3 microns. Recent experiments by Schulz and Tebbens (1941) support these statements. Schulz and Tebbens injected saline suspensions of flint particles containing over 99 per cent. of silica into the ear veins of rabbits. The silica dusts were prepared in four degrees of fineness, viz., of mean particle diameters of 3.3, 1.7, 1.0, and 0.6 microns. For each size group 9 rabbits were used, and each received 400 mg. of dust, injected in two equal doses at 3-month intervals. No animals died from the injections. One from each series was sacrificed at intervals of 3 days to 17 months. In these experiments there was essentially an inverse ratio between the particle size and the resulting degree of injury and fibrosis. The smallest particles, having a mean diameter of 0.6 micron, produced a very striking degree of injury in comparison with those having a mean diameter of 3 microns.

McCrae (1913) found that particles larger than 5 microns rarely occurred in lung tissue; basing his opinion on these observations, Mavrogordato (1940) refers to particles of 5 microns or less as dust of fibrosis-producing size, and mentions what he regards as the minimum harmful dose of such dust in terms of its mass. He concludes that the number and size of the particles that go to make up this mass of air-borne dust are of no particular significance, and believes that the mass distribution of air-borne dust is of greater importance than its size frequency. According to Mavrogordato, the finest particles exert an influence proportional to their weight. This view is not borne out by the work of Schulz and Tebbens, for each of the four sizes of dust used by them was of silicosis-producing size by Mavrogordato's standard, yet the finer particles were much the more harmful. The results of Schulz and Tebbens are rather in accord with the view that the injury caused is proportional to the surface area of the dust, or they may indicate that the injury caused by small particles is even greater than would be judged by the surface area.

One other question has been raised concerning the influence of particle size on the dust hazard. That is the relation between particle size and the quantity of dust retained in the lungs. It has been shown by Brown (1931) that the percentage of the inspired dust retained in the body is inversely proportional to the respiration rate, up to a rate of 20 per minute, and directly proportional to the particulate size and to the density of the dust. More recently, van Wijk and Patterson (1940) have determined the percentages of particles of various sizes removed from dust-laden air by breathing. About 25 per cent. of particles of size 0.2 micron, and about 80 per cent. of size 2 microns, are removed, and at a size of 5 microns the percentage removed reaches 95. These authors remark, however, that the larger particles will tend to be deposited in the larger air passages, and that with decrease of size there will be a tendency for the particles to be deposited in the smaller air passages; it is concluded that, owing to the subsequent expulsion of particles from the larger air passages by physiological mechanisms, the size distribution of the dust in the inhaled air may, after all, be some guide to the size distribution of the dust ultimately retained by the lungs.

From this discussion it appears likely that the fibrosis-producing dust particles are those below 5 microns, or almost certainly below 10 microns, in size, and that the smallest particles that can be discriminated by the light-field method of counting under the high-power microscope may play an important part. If this be accepted, there remains the question of how the dust should be measured. It would appear that a more satisfactory measure than the particle count would be the mass concentration of dust below a stated size (3, or 5, or perhaps 10 microns), or perhaps, in view of the recent work of Schulz and Tebbens, the surface area presented by the dust in unit volume of the dust cloud. How far the mass concentration for such a limited range of particle size, or the surface area, can be predicted from the particle count is discussed below.

(b) Relation between particle counts and mass concentrations

If the particles comprising a dust cloud were all of the same material and of uniform size, the mass concentration would be exactly proportional to the numerical concentration, and neither method of quantitative expression would have any special advantage over the other. But in practice the dust particles vary considerably in size and often in composition, and in some dust clouds the size distributions of the different kinds of dust of which the cloud is composed differ considerably. Thus, the dust particles in the air of coal mines vary very much in size, and the particles of minerals other than coal are on the whole of smaller size than the particles in the coal fraction of the dust. The size distribution varies considerably from sample to sample, and this variability reduces the correlation between the mass concentration and the number of particles per unit volume.

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It has been said (Bloomfield and Dalla Valle, 1935) that high correlations exist between counts and weights, and this statement is supported by correlation coefficients for groups of samples of various types of industrial dusts, viz., bituminous coal, anthracite, granite, metal grinding and polishing, and cement. The coefficients of correlation between particle counts and weights for the dusts in the order named are 0·85, 0·77, 0·76, 0·70, and 0·69. The coefficients are, in fact, fairly high, showing that on the whole the higher counts were associated with the greater mass concentrations, but they are not high enough to enable either of the indices to be estimated from the other with any great accuracy. Thus, if from the individual particle counts in the five series of observations the corresponding mass concentrations were estimated by using the appropriate regression equations, the root-mean-square errors of the calculated from the observed masses would still be 53 to 72 per cent. of the errors that would have been incurred by assuming that in each series the mass concentration was in every case equal to the average of the observed values.

We have used some of the data obtained in the present field investigation for a statistical study of the relations between particle counts and mass concentrations. Two series of observations were used—(a) 32 observations in which thermal precipitator and naphthalene filter samples were taken simultaneously, and (b) the averages of 30 groups of thermal precipitator samples taken at various collieries and under varying conditions. From the thermal precipitator data for both series of observations, mass concentrations were calculated, in the manner to be described in a later section (p. 17), for the dust not exceeding 5 microns in size. In the case of the second series, for which naphthalene filter values were not available, the mass concentration of the total dust was also calculated. These mass concentrations of the whole dust and of the dust up to 5 microns in size have been correlated with the total particle counts and with the counts of particles larger than 1 micron, both counts being evaluated from the thermal precipitator samples. The mass concentrations of the total dust and of the dust not exceeding 5 microns in size have also been correlated with each other.

The correlation between the mass of particles of all sizes and that of particles up to only 5 microns in size is not a close one (r is 0·70 and 0·43 for the two series). On the whole, a high total mass concentration indicates that the mass of dust up to 5 microns is also relatively high, but neither of these two coefficients is high enough to allow of the accurate prediction of one mass from the other. Thus, it appears that even when the mass concentration is ascertained directly by a gravimetric method the result obtained in an individual case does not give a good indication of the mass of particles not exceeding 5 microns in size.

It was found that more than 50 per cent. of the total particles counted were below 1 micron in size, but in spite of their number these particles had only a small effect on the total mass of the dust. Hence it appeared that a higher correlation between particle count and mass concentration might be obtained by omitting from the count all particles smaller than 1 micron. This expectation was fulfilled. Correlations between the total particle count and the mass concentration for the total dust were low in both series ($r = 0·47$ and $0·20$), and the coefficient in the second series was statistically insignificant. The correlations between total mass concentration and the count of particles not less than 1 micron in size were higher ($r = 0·62$ and $0·38$) but not high enough to be of any practical use for prediction.

When the influence of the larger particles was excluded and the mass concentrations were calculated for particles not exceeding 5 microns in size, the correlations between particle count and mass were distinctly higher. In the two series the coefficients of correlation between the total particle count and the mass of particles up to 5 microns were 0·95 and 0·76, while when the

count of particles not less than 1 micron in size was correlated with this mass coefficients of 0.99 and 0.97 were obtained.

The foregoing statements relate to the whole dust, but further examination shows that when the two fractions, (a) coal and (b) minerals other than coal, are taken separately, there are still high correlations between the counts of particles not less than 1 micron in size and the masses of particles not exceeding 5 microns in size. Thus, in the second series of data, which includes the results obtained at a number of collieries, the coefficient of correlation between these two variables was 0.97 for each of the two fractions of the dust.

In Fig. 1 the observations that yield these coefficients have been plotted. The lines in the diagrams have been drawn from the equations :—

$$\left. \begin{array}{l} \text{Mass of coal particles not} \\ \text{larger than 5 microns} \end{array} \right\} = \left\{ \begin{array}{l} 0.015 \text{ (No. of coal particles} \\ \text{not less than 1 micron)} \dots \end{array} \right. \quad (i)$$

and

$$\left. \begin{array}{l} \text{Mass of particles of minerals} \\ \text{other than coal, not larger} \\ \text{than 5 microns} \end{array} \right\} = \left\{ \begin{array}{l} 0.017 \text{ (No. of particles of} \\ \text{minerals other than coal,} \\ \text{not less than 1 micron)} \dots \end{array} \right. \quad (ii)$$

The observation points mostly lie quite close to these lines*.

The accuracy of prediction of mass concentration from particle count has been tested by calculating from each of the 30 observed particle counts the appropriate mass concentration, and then determining the root-mean-square error of the calculated from the observed mass concentrations. For the coal fraction of the dust the root-mean-square error of estimation was 3.4 mg., or 19.3 per cent. of the mean observed mass concentration of 17.6 mg.; while for the non-coal fraction the error of estimation was 1.28 mg., or 30.5 per cent. of the mean observed mass concentration of 4.2 mg. These mean errors of estimation are largely due to a few observations in which high or relatively high dust concentrations were found. If prediction is confined to a range of more moderate concentrations, such as should not be exceeded if every possible effort were made to control the dust, the error of estimation is substantially diminished. Thus, taking the 16 observations in which the number of coal particles not less than 1 micron in size did not exceed 1,000 (*i.e.*, in which the mass concentration of particles not exceeding 5 microns in size was not more than 15 mg.), the root-mean-square error of estimation is only 0.7 mg., or 9.3 per cent. of the mean mass concentration of 7.5 mg. Similarly, in the case of the non-coal fraction of the dust, when the calculations are confined to those 16 observations in which the number of particles exceeding 1 micron in size was not greater than 200 (*i.e.*, in which the mass concentration of particles not exceeding 5 microns in size was not more than 3.4 mg.) the root-mean-square error of estimation was reduced to 0.44 mg. or to 21.0 per cent. of 2.1 mg., the mean observed mass concentration in the range considered. When account is taken of the substantial variations in dust concentrations that occur, it will be appreciated that even when the two fractions of the dust are taken separately their mass concentrations for the range of particle size considered can be estimated, with a degree of accuracy sufficient for all practical purposes, from the counts of particles not less than 1 micron in size.

(c) Relation between particle counts and surface area particles

Very similar results were obtained when particle counts were correlated with the surface areas of the dust particles in unit volume of the dust clouds. The surface of all the particles, or that of the particles not exceeding 10 microns, is more closely correlated with the count of particles of not less than 1 micron

* The regression equations calculated from the correlation coefficients were of the form $y = ax + b$. The added constants were in both cases very small, and since, in fact, if there are no dust particles there can be no mass of particles, the equations have been adjusted so that the lines drawn from them pass through the origin.

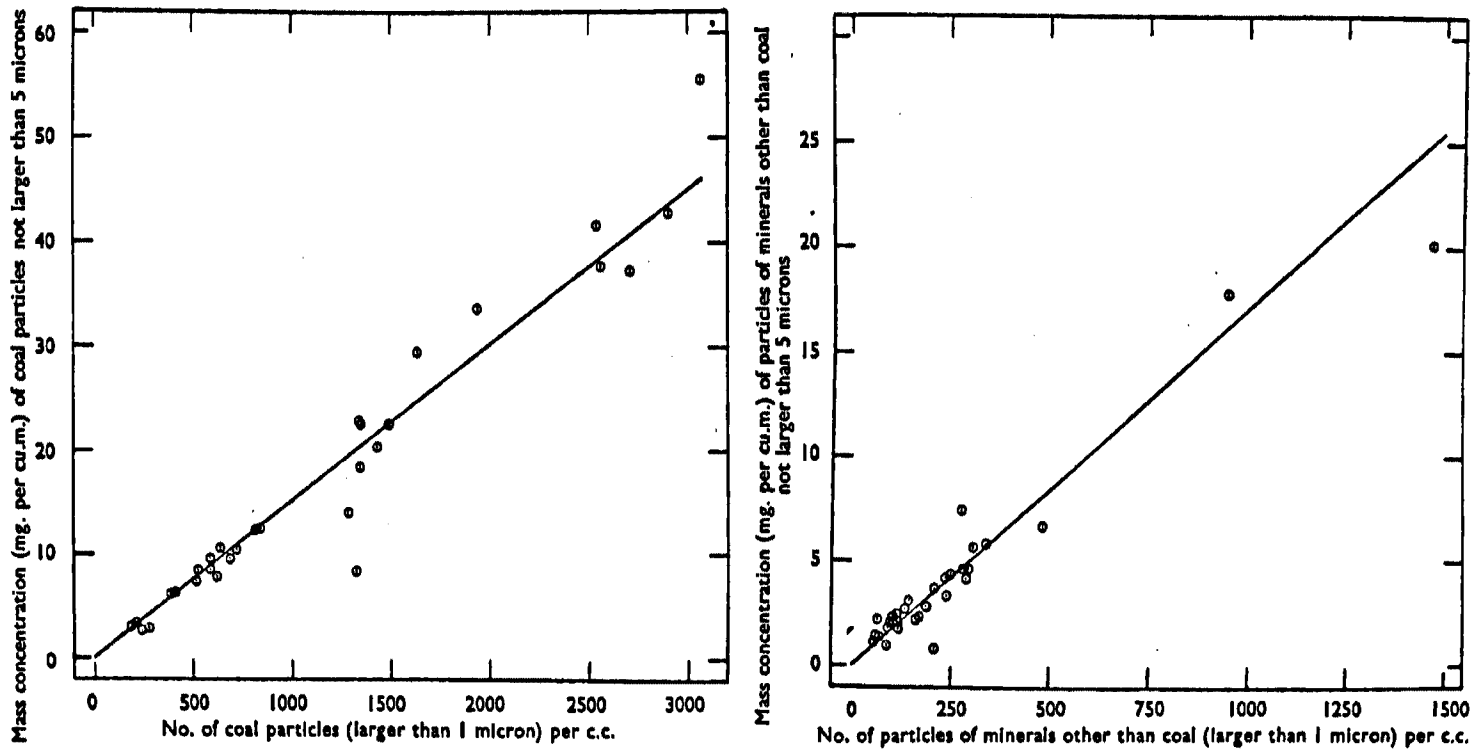


FIG. 1.—Correlation between numerical concentration of particles not less than 1 micron in size and mass concentration of particles not larger than 5 microns.

diameter than with the total count as yielded by the thermal precipitator technique. The surface of particles not exceeding 10 microns in size is more accurately predicted than the surface area of particles of all sizes, and from the count of particles larger than 1 micron the surface area of particles within this restricted size range is ascertainable with considerable accuracy.

(d) Conclusions

The correlations of total particle counts with total mass concentrations reported above are much lower than those obtained by Bloomfield and Dalla Valle. The difference is almost certainly explained by the different methods of dust sampling and the different microscopic techniques employed. The counts given by Bloomfield and Dalla Valle were obtained by the standard impinger technique, and with that method few particles smaller than 1.0 or perhaps 0.8 micron are counted. On the other hand, in the thermal precipitator samples taken in this investigation roughly 50 per cent. of the particles counted were below 0.8 micron in size. We have shown that when only the particles larger than 1 micron are included in the particle count a high correlation is obtained between count and mass concentration, and it is reasonable to assume that if impinger sampling had been adopted in this investigation the particle counts would have correlated well with the mass concentrations.

The impinger technique has been criticised on the ground that the particle count yielded by it does not take into consideration the numerous very small particles which occur in industrial dust clouds, but it appears that this shortcoming is actually an advantage when dust counts are required as indices of mass concentrations. Similarly, the surface area of the dust particles is probably more accurately indicated by the impinger count than by the more exact count given by the thermal precipitator. The high correlations observed between the counts of particles of 1 micron or larger diameter and the mass of dust not exceeding 5 microns in size support the view expressed by Drinker, and referred to earlier, that dust counting as it is done in the United States to-day (*i.e.*, by the impinger methods) provides an estimate of the silicosis risk.

Another point of importance is the relatively low correlation between the total mass concentration and the mass of particles up to 5 microns in diameter only. It may be that in industries other than coalmining extremely few particles larger than 5 microns are found, and the two mass concentrations may thus be more highly correlated than in the present observations. But the low correlations observed by us raise the question whether direct gravimetric observations are of much hygienic significance in the special case of coalmines. It appears that more accurate information as to the mass concentration of the presumably harmful dust can be obtained by the readier method of counting the particles larger than 1 micron in diameter.

4. Methods used in the present investigation

In the present survey dust samples were obtained by means of the thermal precipitator. The sampling technique described by Green and Watson (1935) and by Watson (1936) was employed. The sampling time was chosen so that the deposited particles did not overlap and yet were not too sparse to yield accurate estimates of the dust concentrations; generally the time of sampling was from 10 to 20 minutes.

(a) Treatment of samples

For the removal of smoke and soot particles from the deposits on the cover slips, Green and Watson recommend that before the slips are mounted they should be heated to 500°C. and these particles thus incinerated. Watson, referring to sampling in metalliferous mines, remarks that mine air often contains many particles of acid-soluble material, which are traceable to the water used in drilling. He recommends that the samples be acid-treated after

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incineration, so as to remove the soluble particles. We have been unable to follow these procedures, for it was essential that we should include all the coal particles in our measurements of dust concentrations. At the beginning of the investigation the possibility of incinerating and acid-treating one cover slip from each sample was considered, but it was found that, if the deposit on the untreated slip was not too dense to be counted, the particles on the treated record were too sparse to give a reliable count. Furthermore, when records containing large particles of coal were incinerated there remained ghostly outlines of the original particles surrounding numbers of extremely fine particles, presumably of ash. It is unlikely that these very fine particles would ever be released from the coal in the lungs, and therefore even if it had been practicable to count them the results would probably have given a misleading idea of their pathological significance. At the coalface we never saw wet-drilling, and there is no reason to think that extraneous acid-soluble particles were present in sufficient numbers to affect the accuracy of our dust measurements; nor did smoke or soot particles constitute a problem, for in none of the collieries were naked lights used.

After sampling, the untreated cover glasses were mounted on slides, for examination under the microscope. A 2 mm. oil-immersion apochromatic objective, N.A. 1.37, and a $\times 15$ eyepiece were used, giving an overall magnification of about 1200. For the measurement of particle size the special eyepiece graticule described by Patterson and Cawood (1936) was used. The source of illumination was a 100 c.p. Pointolite lamp with a blue-green filter.

(b) Evaluation of samples

i. *Particle counts and size distributions.*—The thermal precipitator was used primarily to obtain full information about the numerical concentrations of the dust particles and about their size distributions. Particles less than 0.2 micron, and probably down to about 0.16 micron, in diameter were discernible, and the largest particles observed in any of the samples were about 50 microns in size. Throughout this report the numerical concentration of dust particles is expressed as the number of particles per c.c. of the dust cloud; these numbers can be converted to millions of particles per cubic foot by dividing by 35.3.

The size distribution of the particles in each sample was measured with the aid of the eyepiece graticule already referred to. On the graticule are circles of apparent diameters ranging from 5 microns to 0.2 micron, and the particle sizes were estimated by comparison with these circles. The particles were often irregular in shape and, for estimation of their size, they were treated as equivalent circles; that is to say, the cross-sectional areas of the particles were compared with the areas of the circles in the graticule. Not less than 200, and generally about 300, particles were measured in each sample. The numbers or percentages of particles less than 0.2 micron, larger than 5 microns, and in nine intermediate size groups were ascertained. The measured sizes of particles larger than 5 microns were noted for other calculations.

ii. *The nature of the dust.*—Chemical analyses and ash determinations on samples of dust collected on filters give information concerning the nature of the whole dust, but they do not indicate the composition of fractions of the dust of specific particle sizes. Particles of individual minerals can be identified under the petrological microscope, but in its application to the study of air-borne dusts this method has severe limitations. Some minerals with similar optical characteristics cannot be distinguished from one another in sizes below 10 microns, while for quartz the lower limit of discrimination is about 2 microns (Bloomfield, Hatch and Williams, 1938).

It will be shown later, however, that of the dust particles present in the air of the mines examined by us, 75 per cent. or more are commonly less than 2 microns in size, while only 3 to 5 per cent. exceed 5 microns. Hence only a small proportion of the particles could be identified by the usual petrological methods.

At the beginning of this study it appeared that in the thermal precipitator records it was generally possible to discriminate between the coal and other particles, for what we interpreted to be anthracite particles, even down to very small sizes, were quite black, whereas the other minerals were not black and had a glassy appearance. The validity of this discrimination was tested by the examination of a number of preparations.

Professor Briscoe kindly supplied us with slides of the minerals separated from some of his samples of air-borne dusts by a flotation process. On the "coal" slides all the particles were similar to those that we assumed to be anthracite in our records, while on the "non-coal" slides such black particles were but very rarely visible.

As a further check, samples of various minerals were ground in a mortar, and slides were prepared for microscopic examination. A slide of anthracite taken from the Stanlyd Seam at Colliery A.3 showed nothing but black particles. Other slides prepared from various clods from Collieries A.3 and A.4 all showed glassy particles, with solitary black particles appearing only very rarely. Even a slide prepared from what has been described as "coaly-clod" showed particles that were almost wholly non-coal according to our discrimination; in this sample even the small particles appeared glassy, and although some of the large ones appeared rather dark, they lacked the dense blackness which we associated with coal. Similar examination of a sample of "upper bord coal" (an inferior coal) showed that the dust was mainly coal, but there were also a fair number of other particles.

These comparisons appeared to justify the visual discrimination of coal from other minerals in the examination of our samples, and the distinction was therefore made as a matter of routine. Many particles less than 0.4 micron in size could be so classified, but it was not possible to discriminate with certainty particles as small as 0.2 micron, and we therefore only classified particles of 0.4 micron or greater size.

iii. *Mass concentrations.*—From knowledge of the number and size frequency of dust particles derived from thermal precipitator records it is possible to calculate the mass concentration not only of the whole dust but also of the particles within various size ranges, and we have made such calculations for various groups of observations. These calculations have been made for the coal and non-coal fractions separately, and for the whole dust. It has been assumed that the particles were spherical. The average specific gravity of the minerals other than coal has been taken as 2.50, while for the coal fraction we have used values of from 1.35 to 1.45 for different collieries. We are indebted to Mr. D. Hicks, Officer-in-Charge, Coal Survey Laboratory, Cardiff, for information concerning the specific gravities of various coals.

It is desirable that, at the outset, some justification for this procedure should be given. At two collieries thermal precipitator samples were obtained simultaneously with the naphthalene filter samples taken by Professor Briscoe and his colleagues. From each of the thermal precipitator records mass concentrations were calculated, and the results were compared with the corresponding values obtained gravimetrically by the naphthalene filter method. In all, 32 such pairs of samples were obtained. The coefficient of correlation between the mass concentrations given by the two methods was 0.82. The scatter diagram is given in Fig. 2.

The regression line shown in the diagram as a firm line indicates that, on the whole, the masses determined from the naphthalene filter samples were about one and a half times the corresponding values estimated from the thermal precipitator records. The naphthalene filter values were not, however, always higher than those calculated from the thermal precipitator samples. This is shown by the broken line in the diagram, which would have been the regression line if the two methods of estimation had yielded identical results.

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Large dust particles have a great influence on mass concentration, and such discrepancies as are revealed in Fig. 2 are probably due to the inclusion or exclusion of a very few large particles in the evaluation of thermal precipitator

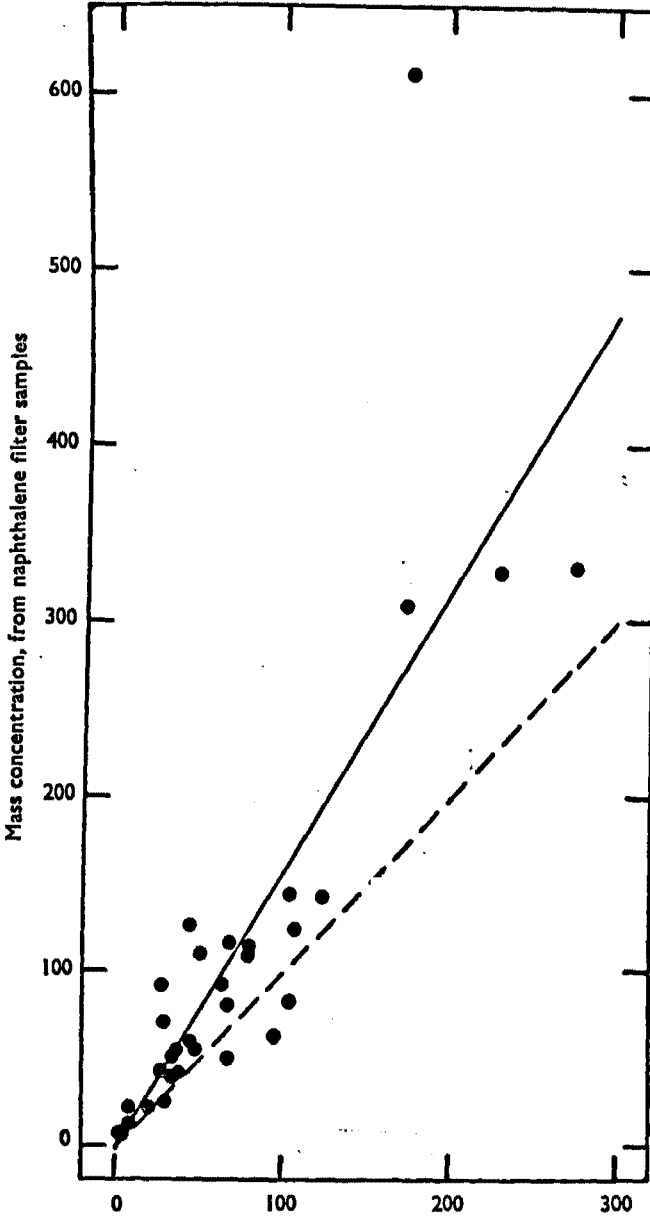


FIG. 2.—Mass concentrations determined from naphthalene filter samples and estimated from thermal precipitator records.

records. It is probable that when mass concentrations are calculated from the averages of considerable numbers of thermal precipitator samples the errors that arise will be distinctly smaller than those which are evident in Fig. 2, and when the estimates are confined to the lower particle sizes only, serious

errors seem unlikely to occur. The estimates of mass concentrations given later in this report are all based on the averages of groups of observations.

It is fairly certain that the discrepancies shown in Fig. 2 cannot be due to any defect of the thermal precipitator as a sampling instrument, for Green and Watson have shown that the size distribution of the particles collected by the thermal precipitator is similar to that given by the sedimentation cell up to a limit of at least 20 microns.

iv. *Surface area of the dust.*—For the averages of various groups of observations we have calculated the surface area of the dust. The area is expressed as sq. mm. per litre. These surface areas have been estimated separately for the coal and non-coal fractions. As in calculating mass concentrations, the assumption has been made that the particles were spherical.

EFFECTS OF VARIOUS FACTORS ON THE AMOUNT AND NATURE OF THE DUST AT THE COALFACE

The amount and nature of the dust at the coalface are influenced by a variety of factors. Amongst these are methods of working shot-firing, the nature of the mining operations, and the presence of moisture. During the course of the investigation observations were made which throw some light on the magnitude of these effects, and it is convenient at this stage to describe this evidence.

1. Effects of methods of working

(a) *Comparison of longwall and narrow working*

One would generally expect to encounter higher dust concentrations in narrow places than in longwall stalls, for there is no through ventilation in a narrow place and consequently the dust produced during mining operations tends to linger, whereas on a longwall face there is through ventilation and even though the air gathers the dust produced in a number of stalls, the actual concentration is often relatively low, on account of the volume of air passing.

From the observations made at Colliery A.3, a comparison of the dustiness of these two types of working place is possible. The majority of the dust samples were taken in longwall stalls, but a few narrow places were still being worked and a number of samples were obtained in them. All the places are in the same seam, and in all of them the coal is hand-got; there are no conveyors at this colliery. The longwall faces were well maintained, the ventilation was generally good, and the conditions were probably fairly typical of longwall stall working in the anthracite field. It cannot be said, however, that the observations made in the narrow places were really representative of conditions where all the coal is got from narrow stalls. The narrow places occurred only singly, so that the air entering such a place was relatively clean and was fouled only by the work carried on in that one place. Consequently, the dust concentrations observed by us in such places must substantially underestimate the concentrations which would ordinarily prevail in a seam worked entirely by the narrow method. This comparison is made in some detail, so that the description may serve to illustrate the methods by which similar comparisons have been made.

TABLE I

Frequency of occurrence of various total dust counts on longwall faces and in narrow places, when no shot-firing was noted. (Colliery A.3.)

Type of working place	No. of observations when total dust count (particles per c.c.) was				Total.	Mean dust count, particles per c.c.
	under 1,000.	1,000 to 1,999.	2,000 to 2,999.	3,000 and over.		
Longwall stalls ..	6	28	11	7	52	1,959
Narrow places ..	0	3	8	9	20	3,421

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Table I summarises the total dust counts observed when no shot-firing was noted. The individual counts varied widely. In both types of place high counts were observed. One sample taken in a longwall stall gave a count of about 6,000 particles per c.c., while the highest count obtained in a narrow place was over 7,000 particles. In the longwall stalls six of the fifty-two samples yielded counts of less than 1,000 particles per c.c., but the counts for the samples taken in narrow places all exceeded that figure. The average counts were 1,959 particles in longwall stalls and 3,421 particles in narrow places. In spite of the variations among individual observations, the data show that the numerical dust concentrations tend to be distinctly higher in narrow places than in longwall stalls, for it can be calculated that differences such as appear between the frequency distributions shown in Table I would not be expected to occur by chance once in one hundred trials.

TABLE II
Average size distributions of dust particles in samples obtained in longwall stalls and in narrow places. (Colliery A.3.)

Size group.	Longwall stalls (52 observations).		Narrow working (20 observations).	
	Percentage of total particles within size group.	Percentage of particles up to maximum size of group.	Percentage of total particles within size group.	Percentage of particles up to maximum size of group.
Below 0.2 micron	9.2	9.2	11.2	11.2
0.2 to 0.4 micron	18.1	27.3	16.6	27.8
0.4 to 0.8 micron	20.4	47.7	24.3	52.1
0.8 to 1.2 micron	12.8	60.5	14.5	66.6
1.2 to 1.6 micron	8.3	68.8	8.8	75.4
1.6 to 2.0 microns	6.0	74.8	5.3	80.7
2.0 to 2.5 microns	4.8	79.6	4.8	85.5
2.5 to 3.0 microns	4.4	84.0	3.5	89.0
3.0 to 4.0 microns	5.6	89.6	4.1	93.1
4.0 to 5.0 microns	4.7	94.3	3.9	97.0
5.0 microns and over ..	5.7	—	3.0	—

The average size distributions for the two groups of samples are shown in Table II. These have been given in two ways: (a) the percentages of the total number of particles within various size groups, and (b) the percentages of particles below certain stated sizes. From this tabulation there appears to be a tendency for the dust on longwall faces to contain a higher proportion of large particles than is contained in that of narrow places, but the differences are inconsiderable, especially when regard is paid to the great variation which occurs in the size distributions of the particles in individual samples. Particles of these large sizes do, however, exert a great influence on the mass concentration of the dust, and the difference noted is enough to have a substantial effect.

On the average, roughly 50 per cent. of the particles in both groups of samples were above or below 0.8 micron in size, and as a test of the significance of the apparent small differences in the average size distributions, it is convenient to consider the proportions of particles below 0.8 micron in size in the individual samples. Table III shows that in both sets of samples the number of particles less than that size varied from under 30 per cent. to over 80 per cent. of the total count. The application of the χ^2 tests shows that the differences between the frequency distributions shown in the table are insignificant.

TABLE III

Frequency of occurrence of samples with various percentages of the total particles counted less than 0.8 micron in size. (Colliery A.3.)

No. of particles less than 0.8 micron as percentage of total count.	Frequency of occurrence in	
	Longwall stalls.	Narrow places.
20 to 29.9 per cent.	9	2
30 to 39.9 per cent.	16	4
40 to 49.9 per cent.	10	2
50 to 59.9 per cent.	8	6
60 to 69.9 per cent.	4	4
70 to 79.9 per cent.	3	1
80 to 89.9 per cent.	2	1
Total No. of samples	52	20

TABLE IV

Frequency of occurrence of various median particle sizes in dust samples taken in longwall stalls and in narrow places. (Colliery A.3.)

Median particle size (microns).	Frequency of occurrence in	
	Longwall stalls.	Narrow places.
0.25 to 0.49	7	2
0.50 to 0.74	7	9
0.75 to 0.99	8	3
1.00 to 1.24	14	1
1.25 to 1.49	9	3
1.50 to 1.74	6	2
1.75 to 1.99	1	—
Total	52	20

Another index of the fineness of a dust is the median particle size. It has already been shown that the size distribution of the dust present in mine air varies considerably, and this variability is reflected in the median particle sizes. In Table IV are given frequency distributions of the median particle sizes of the samples taken in longwall stalls and in narrow places. The values are scattered over a wide range, and on this basis also there is no significant difference between the two groups of observations.

The particles of 0.4 micron or greater size have been classified according as they were judged to consist of coal or of other minerals. The average counts of coal particles larger than 0.4 micron are 1,236 per c.c. in longwall stalls and 2,236 in narrow places, and of those for non-coal particles are 187 and 232 in longwall stalls and narrow places, respectively. The numbers of non-coal particles do not differ significantly in the two types of place, but the coal particles are significantly more numerous in the narrow places. In the individual samples the coal particles considerably outnumbered those of other minerals, but the ratio of the number of coal particles to that of the non-coal particles varies widely in the different samples. The degree of this variability can be seen from Table V. The differences between the distributions shown in the Table are statistically significant; the ratio of the number of coal to that of non-coal particles is generally less on longwall faces than in narrow places.

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TABLE V

Frequency of occurrence of various ratios of the numbers of coal to those of non-coal particles (0.4 micron or greater size) in dust samples taken in longwall stalls and in narrow places. (Colliery A.3.)

Ratio of coal particles to non-coal particles.	Frequency of occurrence in	
	Longwall stalls.	Narrow places.
From 1 to 4.9	13	3
From 5 to 8.9	22	4
From 9 to 12.9	10	5
From 13 to 16.9	3	4
From 17 to 20.9	3	2
21 and over	1	2
Total	52	20

TABLE VI

Average size distributions of coal and other particles in samples obtained in longwall stalls and narrow places. (Colliery A.3.)

Particle size (microns).	No. of particles per c.c.				No. of particles as percentage of No. of coal or of non-coal particles greater than 0.4 micron.			
	Coal.		Non-coal.		Coal.		Non-coal.	
	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.
0.4 to 0.8	327	693	73	139	26.4	31.0	39.0	59.9
0.8 to 1.2	208	158	42	38	16.8	20.5	22.5	16.4
1.2 to 1.6	142	283	20	17	11.5	12.7	10.7	7.3
1.6 to 2.0	104	172	13	8	8.4	7.7	7.0	3.4
2.0 to 2.5	86	154	8	11	7.0	6.9	4.3	4.7
2.5 to 3.0	76	112	11	7	6.1	5.0	5.9	3.0
3.0 to 4.0	102	135	7	5	8.3	6.0	3.7	2.2
4.0 to 5.0	85	128	7	5	6.9	5.7	3.7	2.2
Over 5	106	101	6	2	8.6	4.5	3.2	0.9
Total (over 0.4 micron)	1,236	2,236	187	232	100.0	100.0	100.0	100.0

The average size distributions of the two fractions of the dust are shown in Table VI. It will be noticed that the non-coal fraction contains a greater proportion of fine particles, and a smaller proportion of large ones, than does the coal fraction. This observation applies generally to the samples taken during this investigation. From the right-hand half of Table VI it will be observed that the percentage frequency distributions of the coal particles in the two classes of working place are very similar, but, of the non-coal fractions, that from narrow places has the higher proportion of fine particles (less than 0.8 micron). As a means of testing the significance of such differences as appear in these average size distributions, we have calculated for each sample the percentage of coal or of non-coal particles between 0.4 and 1.2 micron in size, and have then compared the frequency distributions of these percentages. On this basis, the size distributions of the coal particles in the two types of place do not differ significantly, but in the longwall stalls the proportion of coal particles larger than 5 microns was nearly twice as high as in the narrow places, and in these latter places the largest particles seen were 30 microns in diameter, while in the longwall stalls particles as large as 50 microns were observed.

In the case of the non-coal fraction, there is a significantly greater proportion of fine particles in narrow places than in longwall stalls. Inspection of the average particle counts reveals that this excess is confined to particles between 0.4 and 0.8 micron; at sizes above 0.8 micron the numbers of non-coal particles in the two types of place are practically identical.

TABLE VII

Estimates of the average mass concentrations of air-borne dust in longwall stalls and in narrow places. (Colliery A.3.)

Nature of dust.	Mass concentrations of dust (mg. per cub. metre), including particles of sizes :—					
	above 0.4 micron.		0.4 to 10 microns.		0.4 to 5.0 microns.	
	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.
Coal	371.0	209.3	47.0	54.6	12.1	18.1
Other minerals ..	22.8	5.7	4.9	2.4	1.9	1.4
Total dust ..	393.8	215.0	51.9	57.0	14.0	19.5
Other minerals as percentage of total.	5.8	2.7	9.4	4.2	13.6	7.2

Since the numerical dust concentrations in narrow places are distinctly higher than in longwall stalls, while the size distributions of the particles which have been recorded are not very dissimilar, it may be anticipated that in narrow places the higher mass concentrations of dust are likely to be encountered. Estimates of the average mass concentrations for the two types of place are given in Table VII. These estimates have been made (a) for all particles greater than 0.4 micron, and (b) for particles from 0.4 to 5 microns in size. In these calculations the specific gravity of anthracite has been taken as 1.45 and that of the non-coal fraction as 2.50.

The mass concentrations calculated for all particles larger than 0.4 micron are high for both types of working place, but the mass for longwall faces is much greater than that for narrow places: the mass concentration of the total dust is 83 per cent. higher, that of the coal is 77 per cent. greater, and that of minerals other than coal is four times as great on the longwall faces as in narrow places. When the comparison is restricted to particles not exceeding 5 microns in size, however, the results are entirely different. The mass of the total dust is nearly 40 per cent. greater in narrow places than in longwall stalls, the mass of coal is 50 per cent. greater, but that of other minerals is only about three-quarters as much in the narrow places as on the longwall faces. Within this restricted range of particle size the average mass concentration of the total dust is the greater in narrow places, but owing to the low percentage of minerals other than coal (7.2 against 13.6 per cent.) the actual concentration of the non-coal fraction is slightly the less in the narrow places.

The explanation of the great differences between the mass concentrations calculated on the two bases lies in the size distribution of the larger dust particles. Thus, on the longwall faces, of the particles greater than 0.4 micron in size, 8.6 per cent. were larger than 5 microns, while in narrow places only 4.5 per cent. exceeded that size. Of the coal particles greater than 5 microns in size viewed in the samples from longwall faces more than 5 per cent. were 30 microns or more in diameter, and over 1 per cent. were as large as 50 microns. But in the narrow places no particles larger than 30 microns were observed, and the number of these represented only a little over 1 per cent. of the number larger than 5 microns. Divergences of the same type occurred in the sizes of

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the non-coal particles. These figures give a good example of the way in which the mass concentration of dust may be seriously affected by the presence of relatively few large particles.

TABLE VIII

Estimates of the surface area of dust in longwall stalls and in narrow places. (Colliery A.3.)

Nature of dust.	Surface area of dust (sq. mm. per litre), including particles of sizes :—					
	above 0.4 micron.		0.4 to 10 microns.		0.4 to 5.0 microns.	
	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.	Longwall stalls.	Narrow places.
Coal	73.8	73.0	32.1	40.6	15.5	24.1
Other minerals ..	4.5	2.1	2.9	1.6	1.6	1.3
Total dust	78.3	75.1	34.5	42.2	17.1	25.4

Estimates of the surface area of the dust (expressed as sq. mm. per litre) are recorded in Table VIII. When all particles larger than 0.4 micron are considered, the surface area presented by the coal is practically the same in the two types of place, but the area of the non-coal fraction is twice as great in longwall stalls as in narrow places. When particles larger than 5 microns are ignored, the surfaces of the non-coal fractions differ but little, while the area of the coal in the dust of narrow places is more than 50 per cent. greater than that in the dust in longwall stalls.

To sum up, the differences between the dust concentrations in longwall stalls and narrow places are these :—(i) On the average, the total dust count for narrow places is about 75 per cent. higher than that for longwall stalls ; (ii) this difference is due to an excess of coal particles in narrow places, the numbers of non-coal particles being very similar in the two types of place ; (iii) the non-coal fraction of the dust of narrow places tends to contain more very fine particles than are found in the dust from longwall stalls ; the coal fraction shows the same tendency, but the differences are much less distinct and are not technically significant ; (iv) on longwall faces more very large particles (e.g., 30 microns or greater) are found than appear in narrow places ; (v) the estimated mass concentrations of the dust of all sizes are higher for longwall faces than for narrow places, but when the masses are calculated for particles not exceeding 5 microns in size, the mass of coal is 50 per cent. larger in the narrow places and the mass of other minerals is rather less in narrow places than in the stalls ; (vi) the surface area of the dust, taking particles of all sizes into consideration, is practically the same for the two types of place as regards coal, but the area of the non-coal fraction is twice as great on longwall faces as in narrow places ; on the other hand, when only particles up to 5 microns in size are considered, the areas of the non-coal fractions are roughly the same, while that of the coal is over 50 per cent. greater in narrow places than in stalls.

(b) Comparison of stalls and topholes in longwall working

Of the longwall faces at Colliery A.2, some are worked as stalls and others, where the gradient is steeper, as topholes. In tophole working the coal hewn at the face is thrown down the tophole, or chute, to the loading end. Here pit-props are laid horizontally to form a bulkhead behind which the coal accumulates. At intervals the props are withdrawn and the coal is allowed to pour into waiting tubs (or trams). A considerable proportion of the coal is thrown straight into the chute without being shovelled along the coalface, and consequently much of the dust created does not get into the air stream

passing along the face. For that reason, if there is any difference between the dust concentrations in stalls and at tophole faces it may be expected that topholes will be the less dusty.

The average of 21 dust counts made in stalls, 32 at tophole faces, and 5 at tophole loading ends during the loading of coal, are respectively 2,959, 2,503, and 5,569 particles per c.c. Although the average count for stalls is rather higher than that for tophole faces, the difference is not statistically significant. As would be expected, the samples taken at the loading ends of topholes gave a much higher average dust count than the averages for the two groups of coalface observations, but the loading end observations were few in number and no attempt has been made to determine the statistical significance of the higher counts yielded by them. It does appear, however, that during coal loading the air at loading ends is distinctly dustier than that at the coalface. The lowest count at a loading end was higher than the averages for the two coalface groups, and only one of the 53 coalface samples gave a count as high as the average for the 5 samples taken at loading ends.

From the average particle size distributions (tables not reproduced), it appears that the dust in stalls tends to be slightly less fine than that at tophole faces, but when the variations between individual samples are taken into consideration it is found that the average size distributions for stalls do not differ significantly from those for topholes faces in respect of the whole dust or of the coal or the non-coal fractions, nor is there any significant difference in the frequency of occurrence of various ratios between the numerical concentrations of coal and non-coal particles in the two types of place. The average size distributions for loading ends show that the coal dust there is rather coarser than at the coalface; there are proportionately fewer fine particles, while the percentage of particles larger than 5 microns is nearly twice that for the coalface samples.

Tables IX and X respectively show the average mass concentrations, and the average surface areas, of the dust, calculated for stalls, tophole faces, and tophole loading ends. Since the average particle count is higher for stalls than for tophole faces, while, on the average, stalls have the coarser dust, the average mass concentrations and surface areas are the greater in the stalls; but, as there is no significant difference between either the total particle counts or the size distributions for the two types of place, no importance can be attached to the differences in mass concentration or surface area. The mass and surface area of the dust at tophole loading ends are both much greater than those for either type of working place at the coalface.

This comparison shows that longwall faces worked as stalls or on the tophole system are on the whole equally dusty, while there is distinctly more dust at the loading ends of topholes than at the coalface.

2. The effects of shot-firing

The dust-producing effect of shot-firing is generally recognised, and in metalliferous mines, e.g., on the Witwatersrand, arrangements are made for firing to be done in the off-shifts, so that the miners are not exposed to the dust produced. In ganister mines in Great Britain precautions are required against the breathing of air laden with the siliceous dust produced by shot-firing; unless an efficient water blast or other approved means for allaying dust is used, work may not be resumed until four hours after a shot has been fired, and where a water blast is used, up to half an hour must be allowed for the dust to settle or pass away.*

There is no legal restriction on the resumption of work after shots have been fired at the coalface in collieries, and commonly the miners are back at work

* General Regulations, dated 3rd June, 1920, applying to mines in which ganister is worked (1920, No. 873), para. 2.

TABLE IX

Estimates of the average mass concentrations of air-borne dust in longwall stalls and tophole faces and at tophole loading ends. (Colliery A.2.)

<i>Nature of Dust.</i>	<i>Mass concentrations of dust (mg. per cub. metre), including particles of sizes :—</i>								
	<i>above 0.4 micron.</i>			<i>0.4 to 10 microns.</i>			<i>0.4 to 5.0 microns.</i>		
	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>
Coal	95.8	65.9	586.3	58.9	39.8	157.6	24.3	17.1	55.7
Other minerals	2.4	3.1	3.7	2.4	3.1	3.7	1.8	2.0	3.7
Total dust	98.2	69.0	590.0	61.3	42.9	161.3	26.1	19.1	59.4
Other minerals as percentage of total ..	2.4	4.5	0.6	3.9	7.2	2.3	6.9	10.5	6.2

TABLE X

Estimates of the surface area of dust in longwall stalls and tophole faces and at tophole loading ends. (Colliery A.2.)

<i>Nature of Dust.</i>	<i>Surface area of dust (sq. mm. per litre), including particles of sizes :—</i>								
	<i>above 0.4 micron.</i>			<i>0.4 to 10 microns.</i>			<i>0.4 to 5.0 microns.</i>		
	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>	<i>Stalls.</i>	<i>Tophole faces.</i>	<i>Tophole loading ends.</i>
Coal	56.3	39.0	209.2	47.6	32.8	116.1	30.6	21.7	67.8
Other minerals	1.9	2.2	3.3	1.9	2.2	3.3	1.7	1.8	3.3
Total dust	58.2	41.2	212.5	49.5	35.0	119.4	32.3	23.5	71.1

within about five minutes of the firing of a shot. Indeed, on longwall faces they frequently return to work within two minutes of the firing. It should, however, be noted that at Colliery A.1 shot-firing has for some years been restricted to the off-shifts.

In the course of our investigation we took numerous samples directly after shots had been fired, and the results have been compared with data obtained in the absence of shot-firing.

(a) *Colliery A.3.*

At Colliery A.3 seven samples were taken after shots had been fired on longwall faces, and three after shots in narrow places. The average dust counts yielded by these samples are compared in Table XI with the average counts obtained when no shot-firing took place.

TABLE XI

Comparison of average dust counts (a) after shot-firing and (b) when no shots were fired. (Colliery A.3.)

	Longwall faces.		Narrow places.	
	No. of observations.	Average No. of dust particles per c.c.	No. of observations.	Average No. of dust particles per c.c.
No shot-firing	52	1,959	20	3,421
After shot-firing	7	2,882	3	6,548
Percentage excess after shot-firing..	47		91	

In both types of working place substantially higher dust counts were observed after shot-firing than when no shots were fired. The numbers of samples taken after shot-firing are small, and no great stress can be laid on the percentage excesses shown at the foot of Table XI. It is clear, however, that shot-firing causes a considerable increase in the dust concentration even on a longwall face, for it must be remembered that the figures given do not represent "grab" samples taken immediately after firing. The sampling time was generally about 10 to 15 minutes, even in these observations after shot-firing, and the dust counts obtained represent the average concentrations over that period. Instantaneous samples taken immediately after firing would have yielded far higher counts.

The average percentage size distributions of the particles not larger than 5 microns were practically the same after shot-firing as when no shots had been fired. There were some differences in the incidence of large particles, and these are reflected in the calculated mass concentrations. Table XII shows the estimated mass concentrations for various ranges of particle sizes. The calculated masses for all particles greater than 0.4 micron are greatly influenced by the presence of a few large particles (mostly coal) of irrespirable size, and they can be ignored.

Considering only particles 5 microns or less in size, it will be noticed that on longwall faces the mass concentration after shot-firing in coal was 20.9 mg. per cubic metre, as compared with 14.0 mg. when no shots had been fired. This represents an increase of 49 per cent. due to shot-firing, which figure agrees very closely with the 47 per cent. increase in the total dust count. The percentage increase was practically the same for coal and for other minerals. Taking particles up to 10 microns in size into consideration, the mass concentration after shot-firing was 23 per cent. greater than when no shots were

TABLE XII

Estimated mass concentrations of air-borne dust after shot-firing. (Colliery A.3.)

Type of place and conditions.	No. of samples.	Estimated mass concentrations (mg. per cub. metre) taking into account particles of diameter :—											
		greater than 0.4 micron.				0.4 to 10 microns.				0.4 to 5.0 microns.			
		Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.
Longwall faces :—													
No shot-firing ..	52	371.0	22.8	393.8	5.8	47.0	4.9	51.9	9.4	12.1	1.9	14.0	13.6
After firing of shots in coal.	7	230.2	14.8	245.0	6.0	59.3	4.3	63.6	6.8	18.3	2.6	20.9	12.4
Narrow places :—													
No shot-firing ..	20	209.3	5.7	215.0	2.7	54.6	2.4	57.0	4.2	18.1	1.4	19.5	7.2
After firing of shots—													
(a) in coal ..	2	405.3	2.2	407.5	0.5	146.1	2.2	148.3	1.5	42.9	2.2	45.1	4.9
(b) in roof ..	1	53.9	26.3	80.2	32.8	53.9	26.3	80.2	32.8	8.4	17.8	26.2	67.9

TABLE XIII

Average particle size distributions of total dust on longwall face during the getting and filling of coal and after shot-firing. (Colliery A.1.)

Conditions.	No. of particles per c.c. of size (microns) :—											Total particles per c.c.
	under 0.2.	0.2-0.4.	0.4-0.8.	0.8-1.2.	1.2-1.6.	1.6-2.0.	2.0-2.5.	2.5-3.0.	3.0-4.0.	4.0-5.0.	5.0 and over	
Getting and filling coal ..	300	514	618	475	418	346	261	263	290	250	121	3,856
After coal shots ..	785	1,195	1,231	971	765	497	412	355	361	223	94	6,889
After roof shots ..	1,576	1,599	2,429	1,525	967	713	419	339	462	273	112	10,407

fired. Shot-firing increased the number of fine particles up to 5 microns or thereabouts in diameter, while the larger particles, approaching 10 microns in size, were actually less numerous after shot-firing.

In narrow places the effects of shot-firing on mass concentrations were more substantial, and these effects varied with the nature of the shots. Thus, considering only particles up to 10 microns in diameter, after shots had been fired in the coal the mass concentration of coal dust was greatly increased, while the mass of other minerals was not much changed. On the other hand, the single sample procured after a shot had been fired in the roof gave, for the same ranges of particle sizes, coal concentrations very similar to those found when no shots had been fired, while there was a great increase in the concentration of minerals other than coal.

(b) *Colliery A.2.*

At Colliery A.2 only three observations were made after shot-firing in the coal on longwall faces. These gave total dust counts averaging 5,112 particles per c.c., as compared with an average of 2,684 particles for samples taken when no shots had been fired. The increased counts were mainly due to large increases in the numbers of small particles, especially those below 2 microns in size. The average mass concentration of all particles not more than 5 microns in size was only 14.9 mg. per cub. metre, as compared with an average of 21.9 mg. for 53 coalface observations made in the absence of shot-firing; and the masses of non-coal particles were 0.9 mg. per cub. metre after shot-firing and 1.9 mg. when no shots were fired.

(c) *Colliery A.1.*

Special effort was made to obtain samples illustrative of the effects of shot-firing on a longwall face at Colliery A.1. Eight samples were taken after shots had been fired in the coal, and four after roof shots. The data yielded by these samples can be compared with those from 14 samples taken on the same coalface when no shots had been fired and coal was being got or filled into tubs.

The average total dust count during the getting and filling of coal was 3,856 particles per c.c., whereas the average counts after coal shots and roof shots were 6,889 and 10,407 particles respectively. That the greater numbers of particles after shot-firing were due to increases in the numbers of fine particles is shown in Table XIII, where the average particle size distributions are given.

Particles larger than 4 microns were about equally numerous in the three sets of samples, but after shot-firing, and especially after roof shots, the numbers of small particles greatly exceeded the numbers present during the getting and filling of coal.

The particle-size intervals shown at the head of Table XIII have been chosen for convenience of grouping, but they vary in width, and consequently the numbers of particles shown in the different columns give but a poor idea of the relation between particle size and frequency of occurrence. To show this relation fairly, the frequency of occurrence must be given for equal intervals of particle size. From size distributions such as those in Table XIII, figures showing the relative frequency of occurrence of particles of various sizes can conveniently be calculated by dividing the number of particles in any size group by the size interval of that group in microns. Thus the number of particles per c.c. between 0.2 and 0.4 micron in size during the getting and filling of coal was 514, and the number between 4.0 and 5.0 microns was 250; hence the relative frequencies obtained by dividing 514 by 0.2, and by dividing 250 by 1, are 2,570 and 250. Fig. 3 shows the relative size distributions of the dust during getting and filling, and after shot-firing, calculated in that way. The diagram shows very clearly the effect of shot-firing in increasing the numbers of small particles.

It is of interest to determine the nature of the small particles which so greatly increase the total dust count after shot-firing. This can to some extent be

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ascertained by an examination of the separate counts and size distributions of coal and other mineral particles. Table XIV gives the numbers of particles per c.c. of size greater than 0.4 micron, and their percentage size distributions. After shots had been fired in the coal the number of coal particles larger than

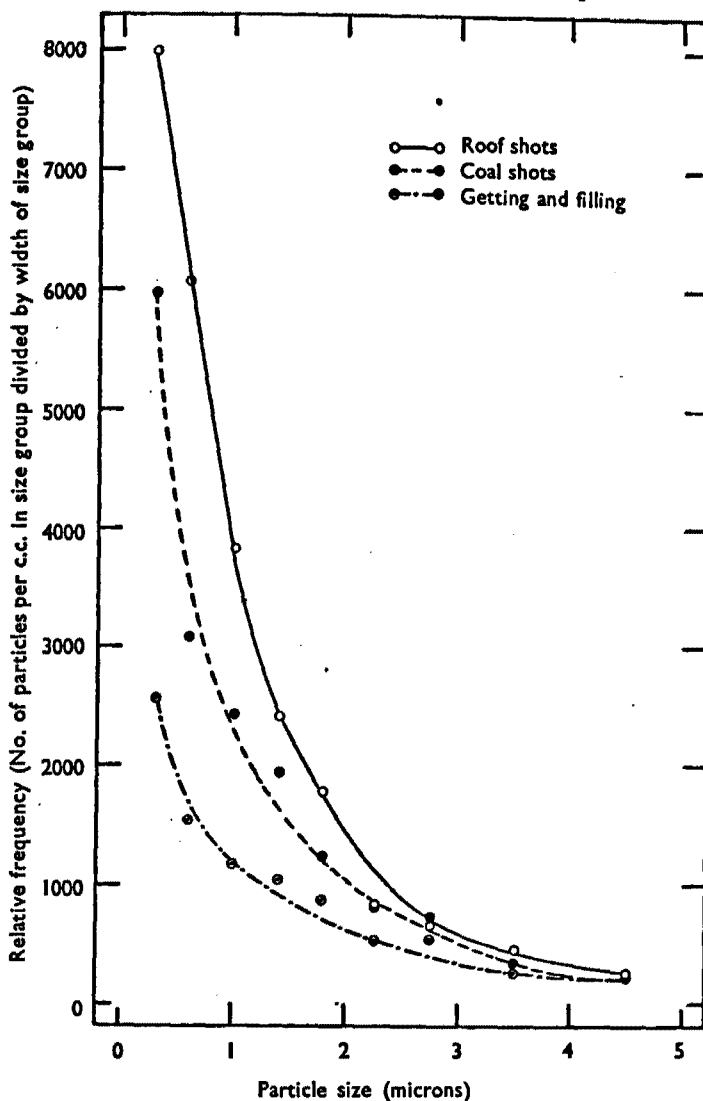


FIG. 3.—Colliery A.1. Effects of shot-firing on relative size distributions of dust particles (total dust).

0.4 micron increased by 56 per cent., and after roof shots the increase was only slightly less, viz., 48 per cent. On the other hand, after coal shots the number of non-coal particles was 81 per cent. greater than during the getting and filling of coal, while after roof shots the excess was 493 per cent. Shot-firing, whether in coal or in the roof, produced coal dust of rather smaller grain size than that found during coal-getting and filling operations, for of the total coal particles greater than 0.4 micron in diameter, 37.9 and 37.4 per cent. were less than 1.2 microns after coal and roof shots respectively, while the corresponding percentage during coal-getting and filling was only 26.8. On

the other hand, shot-firing had no appreciable effect on the percentage size distribution of the non-coal fraction of the dust.

The increase in the proportion of fine particles after shot-firing was due, therefore, partly to the increased fineness of division of the coal fraction of the dust, and partly to the fact that the proportion of minerals other than coal, which produce a fine dust, was much greater after shot-firing than during coal-getting and filling. These facts are illustrated in Fig. 4, which shows the relative frequency of occurrence of particles of various sizes in the coal and non-coal fractions of the dust.

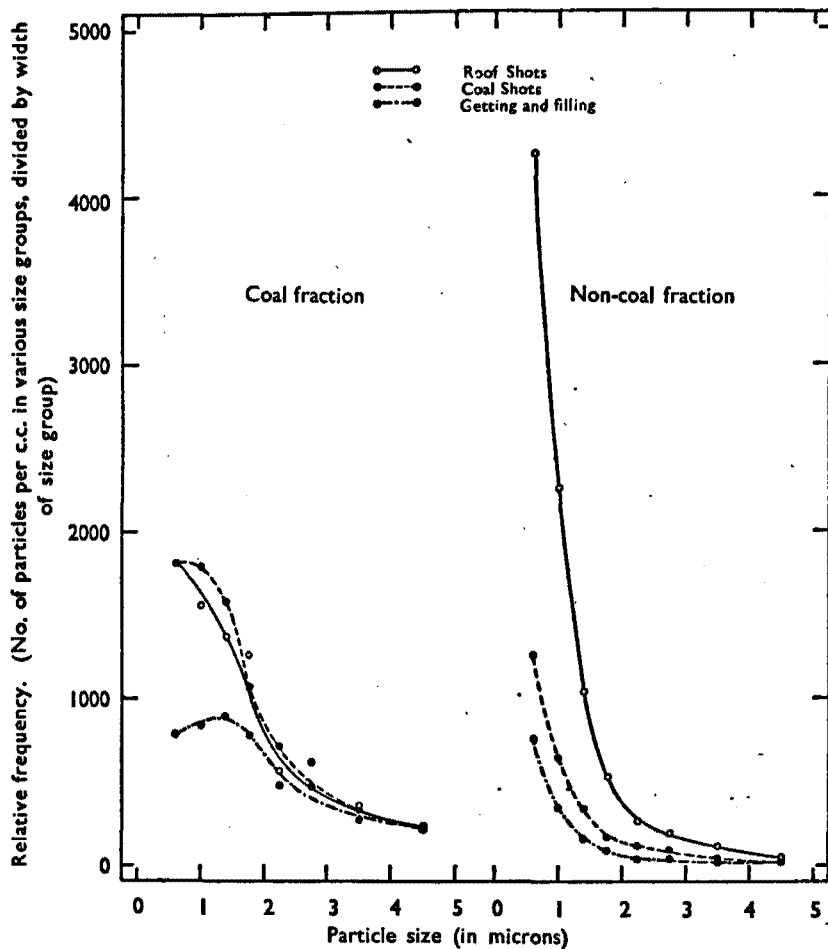


FIG. 4.—Colliery A.1. Effects of shot-firing on relative size distributions of coal and other mineral particles.

The diagram shows, for example, that although the percentage size distributions of the non-coal particles shown in Table XIV are very similar, there was in fact a great increase in the actual number of fine non-coal particles after roof shots.

Estimates of the mass concentrations of dust after shot-firing and during coal-getting and filling are given in Table XV. When all particles larger than 0.4 micron are considered, the total mass concentration was practically the same after the firing of roof shots as during coal-getting and filling; but the composition of the dust was very different, for during coal-getting and filling the minerals other than coal represented only 4.5 per cent. of the total mass,

TABLE XIV
 Percentage size distributions of particles of coal and of other minerals during the getting and filling of coal and after shot-firing.
 (Colliery A.1.)

Nature of dust and conditions.	No. of particles of stated size (microns) as percentage of total number of particles of coal or of other minerals 0.4 micron or more in diameter :—										No. of particles per c.c. of 0.4 micron or larger size.	
	0.4-0.8.	0.8-1.2.	1.2-1.6.	1.6-2.0.	2.0-2.5.	2.5-3.0.	3.0-4.0.	4.0-5.0.	5.0 and over.	Total.		
Coal :—												
Getting and filling coal	13.0	13.8	14.7	12.8	9.8	9.8	11.5	9.7	4.9	100.0	2,430	
After coal shots	19.1	18.8	16.6	11.3	9.4	8.2	8.6	5.6	2.4	100.0	3,799	
After roof shots	20.2	17.2	15.2	14.0	7.9	6.6	9.7	6.5	2.7	100.0	3,602	
Other minerals :—												
Getting and filling coal	49.3	22.7	10.0	5.9	3.6	3.9	1.8	2.5	0.3	100.0	612	
After coal shots	45.5	23.0	12.1	6.1	5.0	4.0	3.2	0.8	0.3	100.0	1,110	
After roof shots	46.9	24.9	11.5	5.8	3.7	2.6	3.1	1.0	0.5	100.0	3,630	

TABLE XV
 Estimated mass concentrations of air-borne dust during the getting and filling of coal and after shot-firing. (Colliery A.1.)

Conditions.	No. of samples.	Estimated mass concentrations (mg. per cub. metre) taking into account particles of size :—											
		greater than 0.4 micron.				0.4 to 10 microns.				0.4 to 5.0 microns.			
		Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.
Getting and filling coal	14	108.7	5.1	113.8	4.5	66.6	5.1	71.7	7.1	33.6	4.2	37.8	11.1
After coal shots ..	8	64.0	7.5	71.5	10.5	64.0	7.5	71.5	10.5	37.3	6.8	43.9	15.0
After roof shots ..	4	79.0	33.7	112.7	29.9	61.3	33.7	95.0	35.5	37.9	20.1	58.0	34.7

whereas after roof shots they made up nearly 30 per cent. of the total. After coal shots the total mass was actually less than during getting and filling, but the mass of minerals other than coal after coal shots was the greater by 47 per cent.

When the effects of large particles are excluded, and only those up to 5 microns in size are considered, a rather different picture is presented. The total mass after coal shots was 16 per cent. and that after roof shots 53 per cent., greater than during the getting and filling of coal. Shot-firing increased the mass of coal dust by roughly 10 per cent., but the mass of the non-coal fraction was increased by 57 per cent. after coal shots and by 379 per cent. after roof shots.

From the foregoing data it is clear that, even on a well-ventilated longwall face, there is, for several minutes after the firing of shots, a considerable increase not only in the number of dust particles but also in the mass concentration of the dust.

The concentration of coal dust is distinctly increased, but there is a much greater proportionate increment in the amount of minerals other than coal, which presumably constitute the more dangerous fraction of the dust; this latter increment is especially great after shots have been fired in the roof.

In narrow places the effects of shot-firing are more substantial than on longwall faces.

(d) *Reduction of dust clouds after shot-firing*

Two obvious ways of reducing the dust concentration following the firing of a shot are: (i) the removal of the dust by the ventilating current; and (ii) its suppression by the use of a mist projector or other effective water spray.

Later in this report the effect of mist projectors in reducing the dust concentrations in mine roadways will be discussed, but no instance of the application of this method of dust suppression at the coalface was met with during the present investigation. It has, however, been shown (e.g. Hay, 1936) that a suitable mist projector is capable of effecting a great reduction in the dust concentration after blasting.

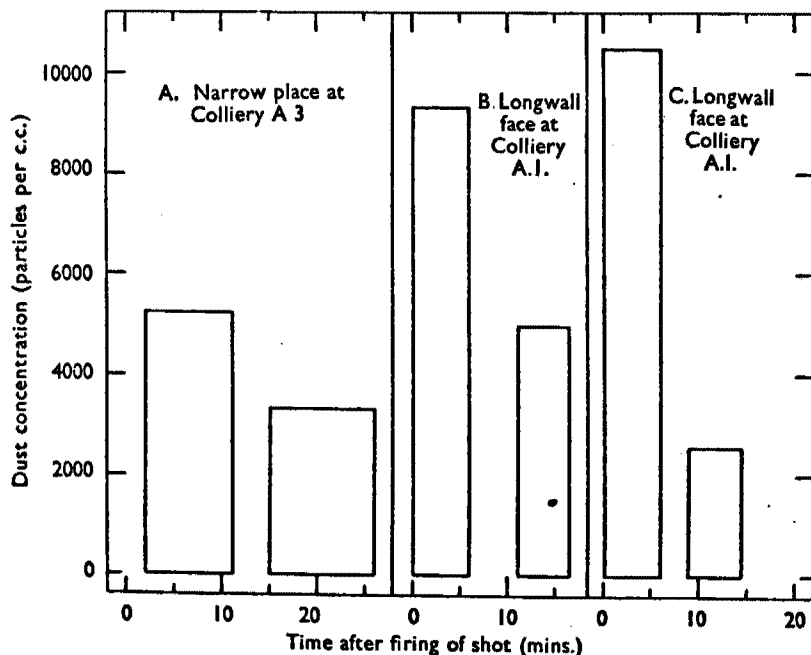


FIG. 5.—Dust concentrations after shot-firing.

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Clearly, the removal of dust by ventilation will be more rapid with copious ventilation than when the air flow is sluggish. Diagrams showing three examples of the decline of dust concentrations after shot-firing are given in Fig. 5. In each case two successive samples were taken in the same place after the firing of a shot; the rectangles show the periods of sampling and the average dust concentrations in those periods. The first example (A) shows the dust concentrations at Colliery A.3, in a narrow place where there was no through ventilation. Examples B and C both relate to a longwall face at Colliery A.1, and both sets of samples were taken in the same stall on the return side of the point where the shots were fired. Even in the narrow place the dust concentration in the second period was considerably less than in the first, but the rate of clearance there was much slower than on the longwall face, where the ventilation was at the rate of about 1,100 cub. feet per minute and the air velocity in the neighbourhood of 60 feet per minute.

Neither of examples A and B shows the full effect of ventilation in reducing the dustiness consequent on firing, for in both these cases coal was being filled during the sampling periods. Nevertheless, the rate of decline was much more rapid on the longwall face than in the unventilated narrow place.

A better illustration of the scavenging effect of ventilation is given by example C, for in that case no work was done while sampling was in progress.

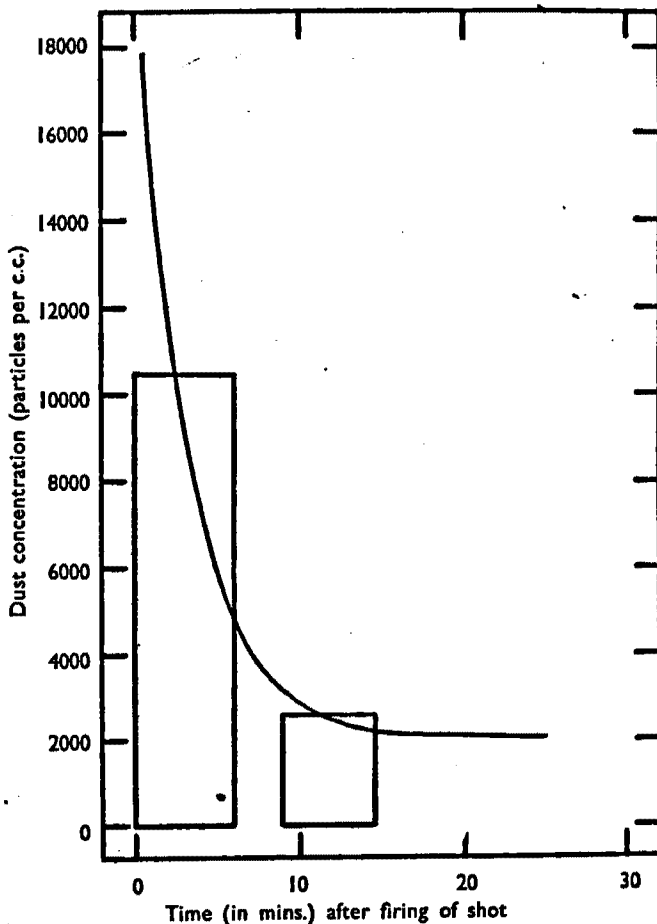


FIG. 6.—Colliery A.1. Effect of shot-firing on dust concentrations on a well-ventilated longwall face.

The average concentration during the first six minutes after the firing of the shot was 10,505 particles per c.c., while between 9 and 14½ minutes after firing the concentration had fallen to 2,568 particles.

The rate at which the dust concentration declined is perhaps shown more clearly in Fig. 6, where a smooth curve has been superimposed on the rectangles which show the observed values. In drawing this curve two assumptions, both of which seem reasonable, have been made. These are that the dust concentration diminished exponentially, and that the concentration in the entering air was 2,000 particles per c.c. It will be noticed that the calculated maximum concentration was nearly twice the average given for the first six minutes, while the concentration ten minutes after firing was only about 50 per cent. higher than that assumed to exist in the entering air.

On a longwall face with ventilation as good as on that under discussion, the miners could avoid inhaling much potentially harmful dust if it were practicable for them to retire out of the air current for about ten minutes after the firing of shots. In worse-ventilated places a longer retirement is desirable.

(3) The dust produced by various operations

(a) *Fluctuations in dust concentrations*

The data presented above show that there was great variation in the individual dust counts. For example, on the longwall faces at Colliery A.3 the mean dust concentration was 1,959 particles per c.c., but counts as low as 542 and as high as 5,994 contributed to that average, and the standard deviation about the mean of 1,959 was 1,044 particles per c.c.

Great increases in dust concentrations due to shot-firing have already been shown, and on a longwall face the effect of blasting may extend for some distance. Thus in a stall at Colliery A.3 the dust count was raised by 42 per cent. as the result of shot-firing 80 yards away on the intake side. But even when no shots are fired the dustiness of a particular working place varies considerably within the space of an hour or two.

Thus, on a longwall face at Colliery A.3, six samples were taken in the same stall during a period of 1½ hours. Five of these yielded counts of 1,569, 2,026, 1,927, 2,013 and 1,577 particles per c.c. The remaining sample, taken between the first and second of those just quoted and while the men in the next place on the intake side were resting and eating their meal, gave a count of only 1,139 particles per c.c., although at that time the men in the place where sampling was in progress were engaged in getting and filling coal, as they were for the greater part of the time during which the other samples were taken.

In another place, at the face of a tophole at Colliery A.2, nine successive samples were taken within a period of two hours. The counts yielded by these ranged from 4,821 to 1,209 particles per c.c., the highest count being given by a sample taken during the shovelling of coal, and the lowest by one obtained at the end of the colliers' meal interval, when no work had been done for nearly half an hour.

Fig. 7 illustrates the variations in dustiness during the space of about 2½ hours in an unventilated narrow place at Colliery A.3. The heights of the rectangles in the diagram show the dust concentrations, and their widths the sampling periods. The diagram also indicates the operations that were being performed during the time of observation. It is of interest that the first sample, taken when the men were getting and filling coal, yielded a much higher count than was observed later in the shift, directly after a shot had been fired. Unfortunately, we have no record of the earlier activities of the men, but it is presumed that the heavy dust concentration noted was probably caused by the pulling down of an overhanging mass of coal. There was a gradual diminution of dustiness towards the middle of the observation period, when little if any dust was being stirred up, i.e., when the men were measuring

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up and, later, when they were taking their meal. After the meal interval the dust concentration again increased, reaching a peak after shot-firing.

Owing to fluctuations such as those just described, it is not practicable to estimate with any reasonable accuracy the average dust concentrations characteristic of each mining operation ; and even if such estimates could be made they would be specific to a particular mine, for dust concentrations vary considerably from mine to mine.

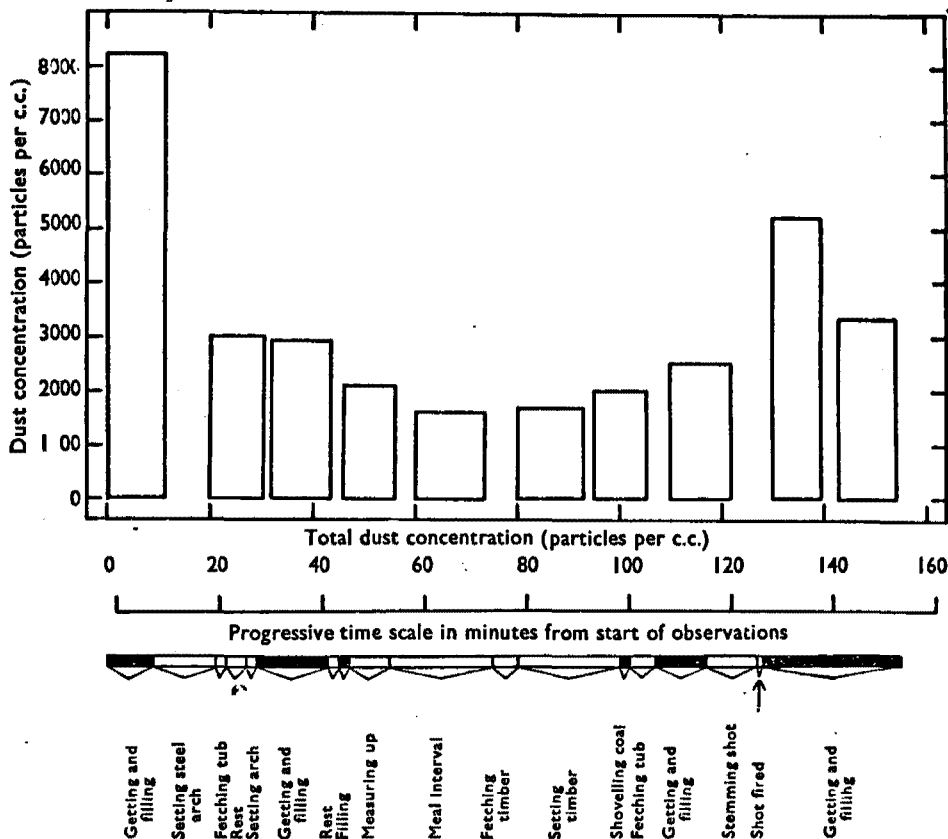


FIG. 7.—Colliery A.3. Variations in dust concentrations in a narrow place.

For individual collieries, however, it is possible to judge whether there is any appreciable difference in the dust produced by different types of work. Thus, in the following section, the effects of handling coal and of ripping are compared.

(b) *The dust produced during coal handling and during ripping*

In many anthracite mines it is the practice for the colliers to do their own face-ripping. They bore any necessary shot-holes, and clear and pack the rippings during their coal-getting shift. Since the rippings consist of material other than coal, it has been suggested that the dust produced by this work may to some extent, and perhaps largely, be responsible for the occurrence of chronic pulmonary disease amongst coalface workers. But, from their X-ray findings and a study of the men's working histories, Hart and Aslett concluded that while the dust produced by ripping might perhaps be a contributory influence in some cases, it was not an essential factor in the causation of the disease (see *Spec. Rep. Ser.*, No. 243).

It is of interest to determine whether the dust produced during ripping operations differs substantially from that caused by the work of getting and filling coal. At two collieries (A.1 and B.3) we obtained a number of samples when rippings were being handled, i.e., when the stone was being shovelled or packed, and the results given by these have been compared with the figures for coal-getting and filling at the same collieries.

Both collieries are worked on the longwall system, and the samples were therefore liable to be affected by the work in progress in other places, but it seemed reasonable to expect that if the dust caused by handling rippings varied substantially from that produced during the getting and filling of coal, the comparisons would reveal significant differences.

(i) *Colliery A.1.*—At Colliery A.1 fourteen samples were taken while the miners were handling rippings, and fourteen while they were getting and filling coal. The averages of the total dust counts for the two kinds of work were very similar, viz., 3,856 particles per c.c. for coal handling and 3,713 for ripping; and the frequency distributions of the individual counts did not differ significantly.

There was, however, a statistically significant difference in the size distributions of the dust particles. On the average, 50.8 per cent. of the particles counted in the ripping samples were below 0.8 micron in size, while in the samples taken during coal-getting and filling only 39.5 per cent. of the particles were below that size. The average median particle size for the ripping samples was 0.83 micron, and that for the coal-handling samples 1.14 micron.

As would be expected, of the two groups of samples, those taken while ripping was in progress contained the greater proportion of dust other than coal. Thus, considering only particles larger than 0.4 micron, the lower limit of our visual discrimination between coal and other particles, the average numbers of particles per c.c. of coal and of other minerals were respectively 1,818 and 796 for the ripping samples, and 2,430 and 612 for the coal-handling samples. These differences are statistically significant.

The size distributions of the coal and of the non-coal particles up to 5 microns in diameter were not significantly affected by the nature of the work. The greater proportion of small particles in the ripping samples noted in the examination of the whole dust was due to the presence of a greater proportion of non-coal particles, for that fraction of the dust consistently contained a greater proportion of fine particles than did the coal fraction. During coal-handling, however, there were more large coal particles, especially those over 5 or 10 microns in size, than during ripping; and, although these particles were not very numerous, they appreciably affected the mass concentrations of the dust.

The estimated mass concentrations are shown in Table XVI, where, for convenience, those for Colliery B.3 are also recorded. The concentrations of minerals other than coal were very similar for the two groups of samples, whether all particles greater than 0.4 micron or only those within a restricted range of size were taken into account. Taking only particles up to 5 microns in size, the two figures were the same; but owing to the smaller amount of coal dust present during ripping, the non-coal fraction constituted a higher percentage of the total dust.

(ii) *Colliery B.3.*—At Colliery B.3 observations were made in the two seams B and M, and these data have been examined separately. In considering the amount of dust other than coal at this colliery, it is to be remembered that the coal is bituminous and routine stone-dusting is therefore carried out. Limestone dust is used for this purpose. In seam B, 35 samples were taken during the getting and filling of coal, and 11 when rippings were being handled. The corresponding numbers of samples taken in the M seam were 48 and 13.

In seam M the average total dust counts for the two kinds of work were practically the same, viz., 1,893 particles per c.c. for getting and filling, and

TABLE XVI

Estimated mass concentrations of air-borne dust during the getting and filling of coal and during ripping

<i>Colliery and conditions.</i>	<i>No. of samples.</i>	<i>Estimated mass concentrations (mg. per cub. metre) taking into account particles of size :—</i>											
		<i>greater than 0.4 micron.</i>				<i>0.4 to 10 microns.</i>				<i>0.4 to 5.0 microns.</i>			
		<i>Coal.</i>	<i>Other minerals.</i>	<i>Total.</i>	<i>Other minerals as percentage of total.</i>	<i>Coal.</i>	<i>Other minerals.</i>	<i>Total.</i>	<i>Other minerals as percentage of total.</i>	<i>Coal.</i>	<i>Other minerals.</i>	<i>Total.</i>	<i>Other minerals as percentage of total.</i>
<i>Colliery A.1</i>													
Getting and filling coal	14	108.7	5.1	113.8	4.5	66.6	5.1	71.7	7.1	33.6	4.2	37.8	11.1
Ripping	14	35.7	4.2	39.9	10.5	33.1	4.2	37.3	11.3	22.2	4.2	26.4	15.9
<i>Colliery B.3</i>													
<i>(i) Seam B</i>													
Getting and filling coal	35	20.5	5.4	25.9	20.8	18.4	5.4	23.8	22.7	9.6	4.6	14.2	32.4
Ripping	11	14.7	7.8	22.5	34.7	12.1	7.8	19.9	39.2	6.2	5.9	12.1	48.8
<i>(ii) Seam M</i>													
Getting and filling coal	48	22.0	2.9	24.9	11.6	19.0	2.9	21.9	13.2	9.6	2.3	11.9	19.3
Ripping	13	13.7	10.0	23.7	42.2	11.5	10.0	21.5	46.5	6.1	5.7	11.8	48.3

2,086 for ripping. In seam B the particle counts were significantly higher for coal-handling than for ripping: the averages were 2,790 and 2,033 particles per c.c. Ripping produced similar average counts in the two seams, but coal-handling caused greater dustiness in seam B than in seam M.

The percentage particle size distributions for the whole dust did not differ significantly. Those for the separate fractions of the dust showed, as usual, higher percentages of fine particles in the non-coal fraction than in the coal, but in neither of the fractions was there any significant difference in percentage size distribution as between the two seams or as between the two kinds of work.

TABLE XVII

Average numbers of particles, larger than 0.4 micron, per c.c. at Colliery B.3

Seam.	Conditions.	Average No. of particles (larger than 0.4 micron) per c.c. of	
		Coal.	Other minerals.
B	Coal getting and filling	1,105	472
	Handling rippings	630	518
M	Coal getting and filling	865	288
	Handling rippings	648	574

Table XVII shows the average numbers of particles of coal and of other minerals, larger than 0.4 micron, for ripping and coal-handling operations in the two seams. During ripping operations minerals other than coal accounted for a substantially higher proportion of the total number of particles than when coal was being handled. The proportions of coal and other minerals during ripping were very similar for the two seams, but during the handling of coal the proportion of other minerals was higher in the B seam.

The estimated mass concentrations, already recorded in Table XVI, were much as might have been anticipated from the particle counts. The mass concentrations during ripping were approximately the same in the two seams. When coal was being handled the mass concentrations of coal dust were almost identical in the two seams; but, for some reason which is not clear to us, the concentration of minerals other than coal was nearly twice as high in seam B as in seam M.

By comparing the estimates of mass concentrations at Colliery B.3 with those at Colliery A.1, it can be seen that the mass concentrations of coal were greater at Colliery A.1. During the work of coal-handling the mass of minerals other than coal was about the same in seam B at Colliery B.3 as at Colliery A.1, but that in seam M was less.

The mass concentrations of minerals other than coal produced by ripping were somewhat higher at Colliery B.3 than at Colliery A.1, but it cannot be said from these data how far routine stone dusting was responsible for the excess. As would be expected, when coal was being handled the concentration of coal dust was in each case higher than when ripping was in progress.

If the effects of ripping on the concentration of minerals other than coal are judged by comparing the figures for ripping with those for coal-handling, it appears that the results were variable. At Colliery A.1 the mass of the non-coal fraction during ripping was the same as, or slightly less than, that during coal-handling, according as the comparison is restricted to particles up to 5 microns in size or larger particles are taken into account. In one seam (B) at Colliery B.3 it was slightly greater, and in the other seam (M) distinctly greater. It can be said, however, that the mass concentration of

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minerals other than coal when rippings are being handled is not necessarily higher than during coal-handling operations; and, judging only from the concentration of this fraction of the dust, it seems doubtful whether the work of ripping constitutes any worse hazard to health than the ordinary work of handling coal.

A possible explanation of the presence of similar concentrations of minerals other than coal during both ripping and coal-handling operations seems to be that even when no ripping is being done there is generally a considerable amount of dirt lying about, and this is disturbed when coal is shovelled. If, after ripping, all the stone, including the small dirt, were disposed of as completely as possible, a reduction might be effected in the amount of stone dust present in the air during other operations. In other industries good housekeeping methods play an important part in the control of dust, and it may perhaps be suggested that in coalmining, too, there is scope for the further application of such methods.

4. Effects of moisture

In that part of the anthracite area where the incidence of pulmonary abnormalities is generally high, the incidence at certain mines is lower than at neighbouring collieries, and it has been suggested that these differences in incidence may be related to differences in atmospheric humidity. The high-incidence collieries are generally reputed to be deeper and drier than the low-incidence mines. It will be shown later in this report that there is some measure of correlation between the average relative humidities at the various collieries and the incidence of X-ray abnormalities in the miners, and it is interesting to ascertain whether there is any connection between atmospheric humidity and dustiness.

(a) *Atmospheric humidity*

The average relative humidities at the coalface at the four anthracite mines included in our dust survey, A.2, A.3, A.8 and A.1, were respectively 94, 83, 77 and 71 per cent. If the particle count be taken as the measure of dustiness, there appears to be a tendency for the drier mines to be the more dusty. The average total dust counts at the collieries in the order named were 2,813, 2,068, 4,310 and 4,302 per c.c., and the numbers of particles of minerals other than coal larger than 0.4 micron were respectively 332, 202, 615 and 788. The mass concentrations of particles not exceeding 5 microns in size were also greater in the two drier mines than in the others: the masses of particles other than coal were respectively 2.0, 2.1, 3.3 and 5.0 mg. per cub. metre, and of all particles up to 5 microns in size they were 24.6, 14.9, 43.2 and 37.3 mg. When particles of all sizes were taken into account there was no apparent relation between mass concentration and humidity. In this comparison, it should be remarked, the average dust concentrations quoted for Colliery A.3 are those for observations made on longwall faces.

These observations suggest that dust concentrations tend to diminish with increasing humidity, but the relation is not a close one. Ventilation and other factors which affect dust concentrations vary from mine to mine, and it is by no means certain from the figures quoted that the variations in dustiness were, in fact, due to differences in the relative humidity of the air.

Another attempt has been made to trace any effect of relative humidity, by comparing the data for three separate districts within the same colliery, A.2. The average humidities and dust concentrations are shown in Table XVIII.

The relative humidities were all high, and the averages for the three districts varied only from 90 to 96 per cent. Owing to differences in air temperature, however, the absolute humidities, expressed as grains of water vapour per pound of dry air, showed greater variation, viz. from 70 to 93 grains. From Table XVIII it will be seen that the dust concentrations, whether expressed as

numbers of particles or as masses, did not vary according to the atmospheric humidity. In 5's district, which had the lowest humidity, the dust concentration was intermediate between those for the other two districts, and 11's district, where the humidity was highest, had the highest dust concentration. These data provide no evidence to support the idea that dust concentrations vary inversely as the atmospheric humidity, but they do suggest that moisture affects dust concentrations in another way.

(b) Wet surfaces

At the coalface the three districts differed considerably in the extent to which visible moisture was present on the rock surfaces. In 11's district slight moisture was occasionally present on the roof, but the face of the coal was practically dry; in 5's district the roof generally appeared moist, but the coalface and floor were always fairly dry; in 3's the roof was always moist or wet, and occasionally the coalface and floor were rather damp. Thus, on the basis of visible moisture, 11's was the driest district, and 3's the wettest.

Inspection of Table XVIII shows that the average total dust count was highest in 11's district and lowest in 3's. The estimated mass concentration of all dust particles up to 5 microns in size was also highest in the driest district and least in the wettest. The numerical concentration of coal particles larger than 0.4 micron in 3's district was only about half that in 11's, and the estimated mass concentration of coal particles, within the range of particle size considered, varied nearly as 4 to 1 between the driest and the wettest districts. The number of particles of minerals other than coal, on the other hand, was greatest in the wettest district; but the variation between the numerical concentrations of non-coal particles was only small, and the estimated mass concentration of the non-coal fraction of the dust was indeed rather lower in the wettest district than in the others. Because of these variations in the mass concentrations of the two fractions of the dust, the percentage of minerals other than coal was much the highest in the wettest district.

Although the numerical concentration of coal particles was much lower in 3's district than in 11's, the difference between the mass concentrations of coal dust was still greater. The explanation of this is that there was proportionately fewer large coal particles in 3's district than in 11's. The relative frequency distributions of particles of various sizes, of both coal and other minerals are shown in Fig. 8. The observed numbers of particles per c.c. between 0.4 and 1.2 micron in size in 11's, 5's and 3's district were respectively 665, 635 and 632 coal particles, and 217, 218 and 268 particles of other minerals. In either fraction these numbers are fairly similar, so frequencies at other particle sizes have been plotted as percentages of the frequency within the range 0.4 to 1.2 micron. Fig. 8 shows that at all sizes above 1.2 micron the number of particles of coal was much less in the wettest district than in the others, while particles larger than 2.5 microns were scarcer in the intermediate district than in the driest.

On the other hand, there seems to be no relation between wetness and the size distribution of the non-coal fraction of the dust.

It appears that the lower dust concentrations in 3's district were due to the presence of moisture on the rock surfaces. It is arguable that moisture on the face of the coal, and perhaps the intrinsic wetness of the coal, to a great extent prevented the dispersion of any coal particles but the smallest, or that if such particles were dispersed they were removed from the air by impingement on the damp rock surfaces.

In a recent paper, Watson (1938) drew attention to the effect of wetness of the surface worked upon the size distribution of the dust particles liberated. For example, the dusts produced by chiselling a block of sandstone (*a*) quite dry, and (*b*) thoroughly wet but with no water lying on the surface, were

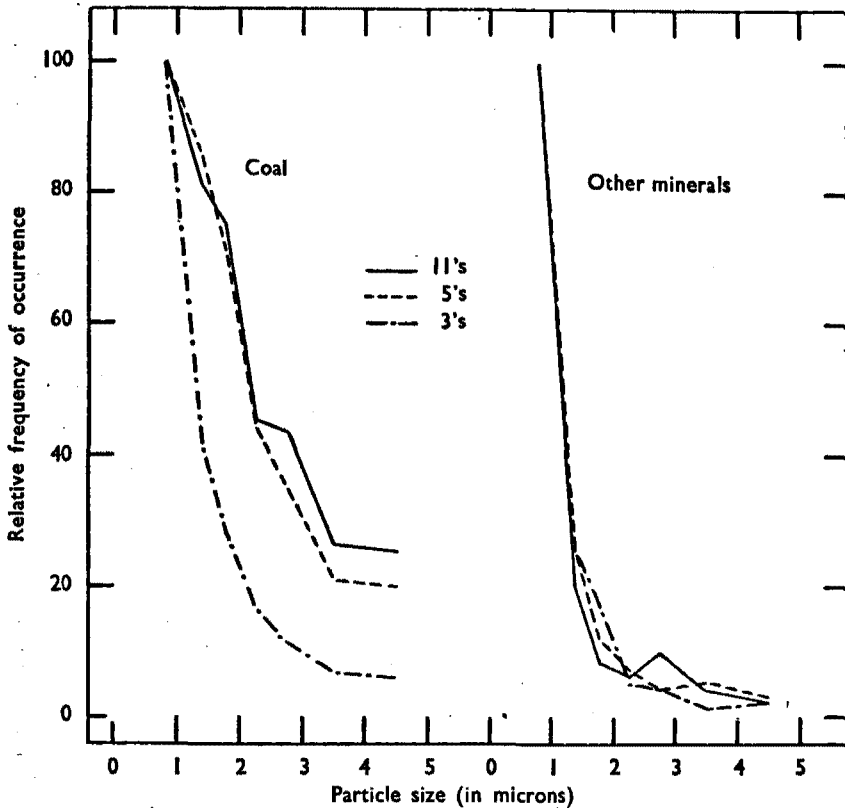


FIG. 8.—Size distributions of dust particles in three districts at Colliery A.2. (The driest district is 11's and the wettest 3's.)

compared. Gravimetric observations on the dust concentrations in the experimental chamber showed that the mass concentration produced by chiselling the wet surface was only about 38 per cent. of that found when the dry block was being worked. On the other hand, the number of dust particles was far greater when the wet stone was worked. The increased count occurred only in the particles not more than 5 microns in size, and especially in the very fine particles below 0.4 micron in diameter. During the working of the dry stone the median particle size was 0.95 micron, but when the wet stone was worked it was only 0.33 micron.

From Fig. 8 it has been seen that the relative frequency of occurrence of the larger sizes of coal particles was less in the wettest district (3's) than in the driest (11's), but in that diagram the particles below 0.4 micron in size were ignored, because the visual discrimination between coal and other particles was not carried below that particle size. The size distributions for the whole dust, however, show not only that particles of the larger sizes were less numerous in 3's district, but also that particles smaller than 0.8 micron were more numerous in 3's than in 11's. The differences between the particle size distributions in the two districts are shown in Fig. 9. In the upper portion of the diagram the numbers of dust particles per c.c. of various sizes are given. The excess of small particles in 3's district is perhaps shown more clearly in the lower part of the diagram, where for various ranges of particle-size the numbers of particles observed in 3's district are plotted as percentages of the numbers observed in 11's. In spite of the lower total count in 3's district, the number of particles smaller than 0.2 micron observed there was twice as

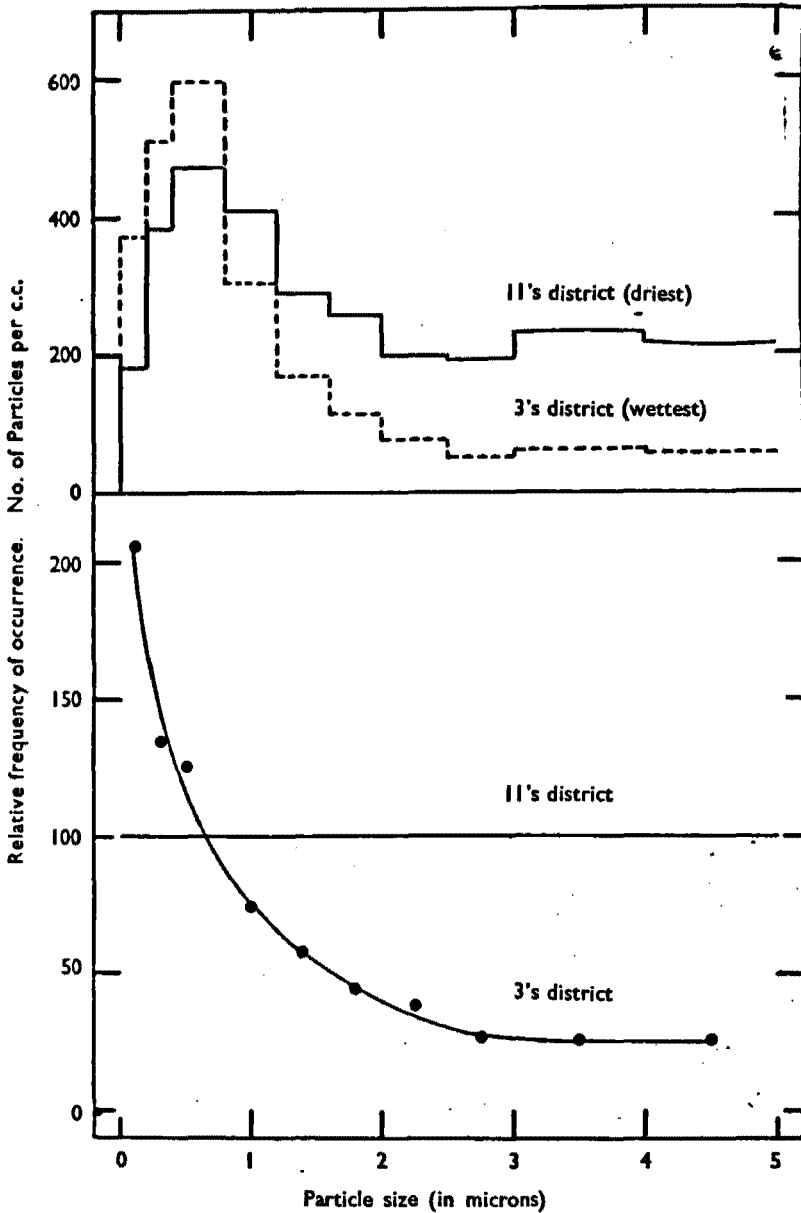


FIG. 9.— Average size distributions of dust particles in driest and wettest districts at Colliery A.2.

large as that found in 11's district, while at 3 to 5 microns the number of particles in 3's was only one quarter of that in 11's. It appears that the size distribution of the dust particles was substantially affected by the presence of wet surfaces: the number of coal particles of the larger sizes was much reduced.

Further evidence of the effect of wet surfaces on dustiness was obtained in the M seam at Colliery B.3. The coalface in this seam was generally dry, but in one small area it was very wet. Water dripped freely from the roof, and in some places water lay on the floor to a depth of several inches. The miners

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wore oilskins and rubber boots. Dust samples were taken in three of these places, and the data have been compared with those from 34 samples taken in other places in the same seam.

The average total dust count in the wet places was 646 particles per c.c., as compared with 2,035 for the rest of the seam. The average numbers of coal particles larger than 0.4 micron were 253 per c.c. in the wet places and 935 in the other, and the corresponding numbers of particles of other minerals were 113 and 310. The reduction in the number of coal particles in the wet places was slightly greater than that of the non-coal particles, but since there were only three "wet" samples this difference is of no significance. In the two groups of samples the average (percentage) size distributions of both coal and non-coal particles were almost identical.

The reduction in numbers of dust particles applied to all sizes and to both fractions of the dust. There was no selective effect on the larger coal particles as was noted at Colliery A.2.

In the three wet places examined the relative humidity averaged 92 per cent., as compared with an average of 85 per cent. for the M seam as a whole. It is unlikely that this difference in atmospheric humidity could account for such a reduction of dustiness as was observed in the wet places, and it is reasonable to conclude that the chief cause of that reduction was the wetness of the rock surfaces.

5. Dust reduction by means of water

Water can aid in the reduction of dust in three ways: (i) by suppressing dust already in the air, (ii) by allaying dust and thus preventing its dissemination, and (iii) by preventing the formation of dust.

(a) *Dust suppression*

Much work has been done in recent years on the use of mist projectors in suppressing dust, especially at loading points and after blasting. For instance, Graham, Skinner and Walton (1939) have shown that the use of a mist projector during and after shot-firing is beneficial in reducing the concentration of dust in the subsequent filling operations, as well as in the actual blasting; and the same authors (1937) had already demonstrated the value of such an appliance in the suppression of dust at loading points.

For the effective removal of dust by this method it is essential that the water be discharged into the air in the form of a very finely atomised spray: a coarse water spray is known to be comparatively ineffective for the purpose.

Observations confirming the ineffectiveness of a coarse water spray for dust suppression were made at the return end of a longwall face at Colliery A.X. A coarse spray was discharged like a curtain across the airway, with the object of washing out nitrous fumes and, while this was in operation, tests were made to determine whether the spray had any effect on the concentrations of air-borne dust. Dust samples were taken on the intake side of the water screen, and again about 15 yards on the return side. In the three pairs of samples the dust counts were 745, 1,161 and 1,129 particles per c.c. on the intake side, and 561, 1,290 and 1,049 on the return side. The average count on the return side (967) was only very slightly lower than that on the intake side (1,012), and no significance can be attached to the difference. In the two groups of samples, too, the average particle-size distributions were almost identical. The water spray had no sensible effect in suppressing dust clouds which had already been raised.

(b) *Dust allaying*

The use of water for allaying dust in mine roadways was investigated by Tideswell and Wheeler (1934). The thorough wetting of coal dust with water alone is often not easy to accomplish, owing to surface tension effects, and these authors showed the value of aqueous solutions of "wetting agents" such as "Permal" and "D.S.103" in facilitating the wetting of dust.

TABLE XVIII

Dust concentrations in relation to atmospheric humidity in different districts at Colliery A.2

District	Mean air temperature (dry bulb, ° F.).	Average atmospheric humidity.		No. of dust samples.	Average dust concentrations.						Ranking on basis of apparent wetness of surfaces at coalface.	
		Relative humidity per cent.	Grs. of water vapour per lb. of dry air.		Total dust count, particles per c.c.	Particles per c.c. greater than 0.4 micron in size.		Estimated mass concentration. (mg. per cub. metre) of particles of 0.4 to 5.0 microns diameter.				Other minerals as percentage of total mass.
						Coal.	Other minerals.	Coal.	Other minerals.	Total.		
11's	66.6	96	83	21	2,930	2,080	285	28.0	1.9	29.9	6.4	Driest.
3'a	60.4	95	74	16	2,338	1,102	350	7.6	1.6	9.2	17.4	Wettest
5's	60.3	90	70	16	2,705	1,869	293	21.9	2.2	24.1	9.1	Intermediate.

TABLE XIX

Effects of watering on numerical concentrations of air-borne dust in mine roadways

Condition of roads.	No. of observations.	Average total dust count, all sizes.	Average number of coal particles per c.c. of size (microns) :—						Average number of particles other than coal per c.c. of size (microns) :—					
			0.4-1.2.	1.2-2.0.	2.0-3.0.	3.0-5.0.	Over 5.0.	Total 0.4 and over	0.4-1.2.	1.2-2.0.	2.0-3.0.	3.0-5.0.	Over 5.0.	Total 0.4 and over.
Dry	13	1,194	181	70	50	50	19	370	183	91	55	68	24	421
Watered	11	885	271	97	51	34	9	462	117	20	10	12	2	161

During the course of our investigation we have obtained further information as to the value of water in laying dust in roadways. Since 1935, mist projectors have been used to lay the dust on the main roads and subsidiary roads at Colliery A.3. The efficacy of this treatment was not in doubt; but in order that we might measure the magnitude of the improvement due to watering, the management readily agreed to carry out an experiment. For from two to three weeks no watering was done on certain roads, so that these might dry out and enable samples representing truly "dry" conditions to be obtained, and later, after the mine had been standing for several weeks, further "dry" samples were taken before watering was recommenced. Samples for comparison were taken as nearly as possible at the same places when the roads had been watered. No wetting agent was used with the water discharged from the mist projectors.

The results are summarised in Tables XIX and XX. The total dust counts were reduced to some extent by watering. This reduction was due to a great diminution in the numbers of particles of minerals other than coal, for after watering there was indeed a rise, though an insignificant one, in the number of coal particles. The results for the individual sampling positions were fairly consistent. It is shown in Table XIX that watering affected the size distributions of the particles; in both fractions of the dust the proportionate numbers of the larger particles were smaller after watering, and this effect was very striking in the case of particles other than coal. Watering had a substantial effect in reducing the mass concentration and the surface area of the dust, and this effect was almost entirely due to a reduction in the quantity of minerals other than coal, i.e., the presumably more harmful fraction, for the concentration of coal was but slightly reduced. Whether particles of all sizes are considered or only the more dangerous sizes, not exceeding 5 microns, the mass concentration of minerals other than coal after watering was only about one-fifth of the concentration when the roads were dry. The effect on the surface area was very similar.

(c) The reduction of dust formation and dispersal at the coalface

Observations described above showed the dust-reducing effect of wet surfaces. They led to the supposition that by a suitable application of water much might be done to reduce the general level of dustiness at the coalface. When rippings are brought down, or when a sizeable lump of coal is got from the face, a more or less dense momentary dust cloud is commonly produced; and during the subsequent stowage of the rippings, or the shovelling and loading of the coal, much dust is dispersed. If, when the rippings or coal were brought down, the material were thoroughly sprayed with water before being further handled, the dust production would probably be greatly reduced. Furthermore, if such wetting were done regularly, any dust which remained on the floor would be damp and less easily dispersed by the initial fall of the material brought down from the roof or face. This wetting would also help to diminish the dispersal during shot-firing. The wetting of rock before removal has been advocated by Haldane (1931) and by Haldane, Haynes, Shaw and Graham (1939); and the value of wetting of all material at the coalface before removal has been stressed by Vossenaar (1940) when discussing the prevention of silicosis in Dutch coal mines.

In bituminous coal mines, Forbes and Emery (1927), and later in a copper mine at Butte (Montana), Brown and Schrenk (1938) showed that satisfactory results could be achieved by spraying blasted material before removal. Brown and Schrenk found that spraying several hours before removal permitted the water to permeate the pile of material and wet it more thoroughly than could the most careful sprinkling of the surface just before shovelling; although spraying just before removal caused a substantial reduction in dustiness, earlier spraying was far more effective.

More recent American observations, made in bituminous coal mines in Utah, have shown that striking reductions in dust concentrations can be obtained by the use of water (Flinn and others, 1941). Thus, in the hand-loading of coal, the average impinger dust count was reduced from 123 million particles per cub. ft. to 5 million (i.e., from 4,342 to 176 particles per c.c.) by wetting the coal and improving the ventilation. There is no evidence to show whether in either of these instances the wetting of the material caused any change in the size distribution of the dust particles.

EXPERIMENTS IN DUST REDUCTION AT THE COALFACE BY MEANS OF WATER

1. Introduction

The American observations quoted in the last section encouraged us to try experiments on the use of water sprays at the coalface in an anthracite mine. In planning the tests, it was decided to use a method of watering that could readily be adopted as a matter of routine, even if the dust reduction thereby effected was less striking than might have been obtained by other methods. Regard had to be paid to the necessity for transporting water from the surface to the coalface, and to the undesirable results that might ensue from a too lavish application of water. Excessive moisture may seriously affect the weathering of the strata and thus cause considerable difficulty in roof control; and in a hot mine copious watering may raise the atmospheric humidity to an uncomfortably high level. For these reasons, it was decided to apply water sparingly.

The first experiment was carried out on a longwall face, and the second in a narrow place. Observations were first made of the dust concentrations under normal, dry, working conditions, and then further observations were made when all hewn material was carefully sprayed with water before it was further disturbed by loading or stowing. The water was stored in casks as near as practicable to the face, and buckets were filled from these as required. The spraying was done by means of A.R.P. stirrup pumps, the fine spray nozzle being used. In the American studies it was shown that spraying the material several hours before removal was much more effective in suppressing dust than even the most careful sprinkling carried out just before removal. In our experiments it was not practicable to leave the material for long periods after spraying. It is the general practice to load the coal or stow the rippings directly after the material has been hewn, and it was thought undesirable to attempt any procedure which would upset normal mining practice. Consequently, in our experiments the water had no chance to permeate the material before it was removed. To compensate for this, as fresh dry surfaces were exposed while a heap of material was being removed, these surfaces were sprayed from time to time; and as coal was loaded, the spray was occasionally applied to the surface of the coal in the tub. On the longwall face, the wetting experiment was carried out in three stalls, and the total consumption of water was at the rate of about 10 gallons per hour, or rather more than 3 gallons per hour per stall. In the narrow place, the water was used a little more freely and the consumption was about 5 gallons per hour. The time spent in spraying was negligible.

The longwall experiment was conducted on a face which an earlier survey had shown to be the dustiest longwall face in the colliery. So that the dust concentrations measured during the period when the water sprays were used would not be affected by dry working in other stalls, the experiment was carried out in the first three places at the intake end of the face: these were the first three stalls on that ventilation circuit. In these stalls observations were made during two days when no wetting was done and then on the next two days, when water was applied in the way already described. In the narrow place

TABLE XX
Effects of watering on mass concentration and surface area of dust in mine roadways

Condition of roads.	No. of observations.	Estimated average mass concentration (mg. per cub. metre) of dust.						Estimated surface area (sq. mm. per litre) of dust.					
		Of all sizes.			Not exceeding 5.0 microns in size.			Of all sizes.			Not exceeding 5.0 microns in size.		
		Coal.	Other minerals.	Total.	Coal.	Other minerals.	Total.	Coal.	Other minerals.	Total.	Coal.	Other minerals.	Total.
Dry ..	13	18.6	35.6	54.2	3.2	7.5	10.7	9.4	11.6	21.0	4.3	5.5	9.8
Watered ..	11	16.6	6.9	23.5	2.6	1.4	4.0	7.7	2.0	9.7	3.9	1.2	5.1

TABLE XXI
The effect of the use of water sprays on the estimated average mass concentrations of air-borne dust in longwall stalls during the getting and filling of coal

Conditions.	No. of samples.	Estimated mass concentrations (mg. per cub. metre) taking into account particles of size :—											
		greater than 0.4 micron.				0.4 to 10 microns.				0.4 to 5.0 microns.			
		Coal.	Other minerals	Total.	Other minerals as percentage of total.	Coal.	Other minerals	Total.	Other minerals as percentage of total.	Coal.	Other minerals	Total.	Other minerals as percentage of total.
Normal dry working ..	18	145.3	3.9	149.2	2.6	74.0	3.9	77.9	5.0	29.0	2.8	31.8	8.8
Water sprays used ..	20	33.8	1.1	34.9	3.2	25.7	1.1	26.8	4.1	12.8	1.1	13.9	7.9
Wetted as percentage of normal		23.3	28.2	23.4	—	34.7	28.2	34.4	—	44.1	39.3	43.7	—

observations of the dust concentrations were made with dry working on one day and with spraying on the next day.

Since the bulk of the miner's time is spent in getting and filling coal, the dust measurements to be described are those made while such work was being performed. No attempt has been made to draw conclusions from the very few observations made during the short periods when other work, such as timbering and ripping, was being done.

That the use of water sprays had no appreciable effect on the atmospheric humidity is shown by hygrometric observations. On the longwall face the air temperature (dry bulb) averaged 67.6°F. Spraying raised the relative humidity by only 1½ per cent., *i.e.*, from 91 per cent. to 92½ per cent.; and the absolute humidity was 91 grains of water vapour per pound of dry air on the "dry" days and 93 grains on the "wet". The very small rise in the humidity observed could not be detected subjectively. In the narrow place, where the temperature was 69°F., the effect of the water sprays was only slightly greater than on the longwall face. The relative humidity was raised from 81 to 85 per cent., and the absolute humidity from 86 to 90 grains of water vapour per pound of dry air.

Throughout the experiments care was taken to ensure that no water was sprayed on to the roof.

2. The dust reduction effected

(a) On the longwall face

Altogether, in the three stalls, 18 dust samples were taken during the getting and filling of coal under normal working conditions and 20 samples were obtained when the stirrup pumps were used for spraying.

i. *Total dust.*—The average dust counts (total dust) observed under the dry and wet conditions were respectively 3,065 and 1,445 particles per c.c. Thus the use of the water sprays reduced the average particle count by 53 per cent. In any mine, dust concentrations vary substantially from place to place, and even in the same place there is considerable variation during the course of a shift. It is therefore of interest to point out that, in the earlier survey of the longwall face on which these trials were carried out, the seven observations made yielded an average total dust count of 2,976 particles per c.c., which figure is very similar to the average of 3,065 particles found during the first experimental period.

The percentage particle size distributions of the whole dust were very similar to the other size distributions tabulated in this report, and it is unnecessary to reproduce them. In the observations on dry working, on the average 4.9 per cent. of the total particles counted were over 5 microns in size; while the corresponding percentage in the observations made when sprays were used was 3.0. Examination of the percentages of particles of this size in the individual samples shows that this difference is statistically significant. At all sizes up to and including 5 microns the percentage distributions in the two groups of observations were almost identical; any slight differences were insignificant.

ii. *Coal and other mineral particles.*—The use of water sprays affected both fractions of the dust to the same extent. In the dry observations the number of dust particles (coal and other minerals) larger than 0.4 micron averaged 2,572 per c.c., and when spraying was done the corresponding average was 1,203. The count of particles above 0.4 micron in size was reduced by the spraying to 47 per cent. of the count yielded by the dry observations. The average counts of coal particles larger than 0.4 micron in the two series of observations were 2,106 and 985, and the counts of particles of minerals other than coal were 466 and 218. In either case the spraying caused a reduction to 47 per cent. of the dry value.

The average percentage particle size distributions for the two fractions of the dust are not reproduced, but scrutiny of them shows that up to a particle size of 5 microns the average size distributions for the dry and wet observations were almost identical. In both fractions of the dust spraying brought about some diminution in the proportion of particles larger than 5 microns.

iii. *Mass concentrations.*—In Table XXI the estimated mass concentrations of coal and other mineral dusts are shown. In the bottom line of the Table the mass concentrations observed during the period when water sprays were used are expressed as percentages of the corresponding concentrations observed under normal dry working conditions. When only the particles up to 5 microns in size are considered, it is seen that the mass concentration of the total dust was reduced by spraying to 43·7 per cent. of the mass observed with dry working. This reduction is very similar to that observed in the particle count, i.e., to 47 per cent. of the dry value. When larger particles are included in the estimated mass concentrations, the reduction due to spraying is more striking, owing to the fact that the reduction in the number of particles larger than 5 microns was proportionately greater than the reduction in the number of smaller particles. Thus, taking into account all particles larger than 0·4 micron, the lower limit of our discrimination between coal and other minerals, the mass concentration of the total dust when the sprays were used was less than one-quarter of that found during normal dry working.

In connection with the suggestions, made later in this report, as to standards of permissible dustiness, it is of interest to note that when the water sprays were used the concentration of particles of minerals other than coal on this longwall face was reduced to only 1·1 mg. per cub. metre.

(b) *In the narrow place*

In the narrow place 6 dust samples were taken while coal was being handled under normal dry working conditions, and 7 were obtained when the water spray was being used. The dust concentrations were very similar to those observed on the longwall face. The spraying of the hewn material reduced the average total dust count to 42 per cent. of the dry value, i.e., from 3,305 to 1,384 particles per c.c. The numerical concentration of coal particles larger than 0·4 micron was reduced by the spraying to 42 per cent. of the concentration observed under dry conditions, and the count of particles of mineral other than coal was reduced to 47 per cent. of the dry value. Thus, the percentage reductions effected by the spraying were practically the same as those observed in the longwall stalls, and the percentage reduction was substantially the same for all sizes of particles. There was apparently no differential effect of the wetting with respect to either the quality or size of the dust particles.

The effect of the wetting on the estimated mass concentrations of the dust was very similar to that recorded in Table XXI. The concentration of coal dust particles not exceeding 5 microns in size was 33·0 mg. per cub. metre under normal conditions and 13·6 mg. when the sprays were used. The corresponding concentrations of particles of minerals other than coal were respectively 3·5 and 1·6 mg. Hence the concentrations of all dust particles up to 5 microns in size were 36·5 mg. per cub. metre for dry working and 15·2 mg. when the sprays were used. Spraying reduced the concentration of dust of this size to about 42 per cent. of the concentration found with normal dry working. As in the case of the longwall face observations, when the larger particles were taken into account the effect of the sprays appeared more striking. In respect of all particles larger than 0·4 micron, the concentration during the period when spraying was done was only about 25 per cent. of that found when there was no spraying.

3. Conclusion

The experiments here described confirm that a very substantial reduction in the concentration of air-borne dust at the coalface can be obtained by using a simple stirrup pump to spray all hewn material with water before it is further handled. The quantity of water used in the experiments was small: it was not enough to make any sensible difference to the humidity of the air in the working places, and since care was taken not to spray the roof, the use of water cannot have had any adverse effect on the weathering of the roof. Further, since the amount of spraying required was small, but little extra work was imposed on the colliers, and the procedure adopted was such as one could reasonably expect men to carry out as a matter of routine, even without close supervision. There can be little doubt that a more copious use of water would have produced much more striking results in the way of dust reduction, but for the reasons mentioned earlier it was felt desirable at the outset to restrict the consumption of water to an amount that would neither inconvenience the management or the colliers, nor adversely affect the roof.

COMPARISON OF DUST CONCENTRATIONS AT THE COALFACE AT DIFFERENT COLLIERIES

1. Introduction

In the American report on Anthraco-Silicosis among Hard Coal Miners (Bloomfield and others, 1936), occupational dust exposures are quoted. Dust samples representative of different mining operations were procured and time studies were made; and from the proportion of time spent at each type of work, and the average dust counts for the various operations, the weighted average occupational dust exposures were derived.

In the light of our previous experience of mining work we felt it unwise to adopt that procedure in the present investigation. Some years ago, in bituminous coal mines, we made many time studies of the activities of coalface workers, and observed that the proportions of working time spent on different operations varied considerably from place to place and as between different miners. Many observations would be necessary to arrive at a reasonably accurate apportionment of the average time spent on the various tasks. Even if that could be done, there would still remain the further difficulty of obtaining reliable figures for the average dust concentrations for individual operations. A miner commonly changes from one form of activity to another at intervals of a few minutes. Where the air movement is sluggish, as so often is the case in narrow places, the dustiness observed while one operation is being performed is partly conditioned by the nature of the work done in the preceding period; for a heavy dust cloud, once raised, may linger. On a longwall face the dust concentration in any stall is much affected by the activities of the occupants of other stalls on the intake side.

For these reasons, we have felt it undesirable to attempt to calculate occupational dust exposures for coalface workers on those lines. Instead, we have relied on obtaining a measure of the general level of dustiness at the coalface at each colliery by random sampling, and have applied statistical tests to determine whether any apparent differences in dust concentrations are significant. Such tests have been applied only to the average numerical concentrations of dust particles and the average particle size distributions. Since mass concentrations and surface areas have not been calculated for individual dust samples, it has not been practicable to make direct tests of the significance of differences between the mass concentrations and surface areas calculated from the average particle counts and size distributions of various groups of samples.

Before we proceed to describe these data, attention should be drawn to a statement made in Part I of this report, namely, that while at some of the

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collieries (A.2, A.8 and B.3) the dust concentrations measured in our survey probably give a good indication of the hazard experienced by the colliers for many years past, at two of the collieries conditions have changed in recent years. Owing to the circumstances mentioned earlier, the dust concentrations measured at Colliery A.1 were substantially lower than those which generally prevailed at the coalface in that colliery several years ago. The dust measurements made on the longwall faces at Colliery A.3 give no indication of the concentrations at this colliery in former years, and even the concentrations measured by us in the few remaining narrow places at this colliery probably underestimate the earlier hazard to a considerable extent. The averages observed in narrow places have, however, been used in this section, as being the best available index of the dust hazard to which the miners were formerly exposed.

At Colliery A.8 dust sampling was done only in the Nine Feet Seam, so that the dust figures for this colliery should strictly be related to the incidence of X-ray abnormalities for that seam only, and not to that for the whole colliery. However, the observed numbers of abnormalities ("consolidations") per cent. of the expected numbers were very nearly the same—146 for the whole colliery, and 154 for the Nine Feet Seam only—so that it makes no material difference which figure is used.

The numbers of samples taken in the different districts at Colliery A.2, and in the various districts in the two seams at Colliery B.3, were roughly in proportion to the numbers of men employed in those districts, so that the average data for the whole collieries fairly represent the average dust exposures.

2. Numerical concentrations of dust particles

For dust control work in some industries, standards of the maximum permissible dustiness have been expressed in terms of the numerical concentration of dust particles. Such standards have been set up in the State of New York for the work of rock-drilling and rock-crushing, and the total particle count by the approved (impinger) technique appears to provide a useful yard-stick with which the dust hazard can be measured. In coal-mining, however, a complication is introduced by the fact that the dust is composed of two distinct fractions, coal and other minerals. As a rule, the coal particles greatly outnumber the particles of other minerals, but the ratio of the numbers of the two kinds of particles varies very much from time to time. In one out of about every thirty of the samples taken at the coalface in this investigation the coal particles were fewer than those of other minerals, but in the remaining samples the coal particles were the more numerous. The proportion of coal particles to others was between 1 to 1 and 3 to 1 in 32 per cent. of the samples, and between 3 to 1 and 5 to 1 in another 29 per cent. In 14 per cent. the proportion was over 9 to 1, and in nearly 2 per cent. of the samples it was more than 21 to 1.

Clearly, the total particle count is by no means an accurate index of the number of particles in either fraction of the dust, and it follows that if the X-ray abnormalities in the lungs of the workers are due to a specific fraction of the dust inhaled, the average total counts for the various collieries will not necessarily rank parallel with the incidence of those abnormalities. On the other hand, it has been suggested that massive doses of any dust are likely to cause injuries to the lungs; and, if this be so, the total quantity of dust present in the atmosphere may be the deciding factor in the causation of pulmonary disease of coal miners.

In an earlier section of this report, it has been emphasised that the dust count obtained in given circumstances depends on the methods of sampling and evaluation used. The point is an obvious one, but it is mentioned again here to remind the reader that the particle counts quoted in this section were

obtained with the thermal precipitator, and that they are substantially higher than the counts which would have been obtained by the impinger technique, or by the use of the konimeter if light-field counting had been adopted.

(a) *Total dust counts*

The average total dust counts at the coalface at each of the five collieries, together with the standard (or root-mean-square) deviations*, are shown in Table XXII, and, for comparison with the dust counts, the relative incidences of X-ray abnormalities are also given. Averages are shown for all observations at the coalface, including those taken directly after shots had been fired, and these probably give the best measure of the average dust exposure in terms of particle counts. However, since at Collieries A.8 and B.3 no shots were fired, it may be thought desirable to compare the figures for these collieries with the averages for the others when samples taken immediately after firing are excluded, and such averages are therefore given on the right-hand side of the table. Owing to the relatively small numbers of observations made after shot-firing, the two sets of averages do not differ very greatly.

TABLE XXII

Average total dust counts at the coalface at various collieries

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	Total dust counts (particles per c.c.).					
		Including samples taken after shot-firing.			Excluding samples taken immediately after shot-firing.		
		No. of samples.	Mean count particles per c.c.	Standard deviation.	No. of samples.	Mean count particles per c.c.	Standard deviation.
A.1	233	(27)	4,302	2,582	(24)	3,832	1,702
A.3	172	23	3,829	2,059	20	3,421	1,772
A.8	146	42	4,310	1,722	42	4,310	1,722
A.2	12	56	2,813	1,382	53	2,683	1,273
B.3	4	118	2,164	863	118	2,164	863

The mean counts shown for Colliery A.1 are not the simple averages of all the observations, including or excluding those made after shot-firing. During the investigations at this colliery special efforts were made to secure samples which would illustrate the effects of ripping and of shot-firing, and therefore the simple average of all the data would give undue prominence to these effects. In this case we have resorted to the calculation of something akin to the occupational figures used by the American workers: we have calculated weighted averages. According to the colliers, the time spent by them on ripping operations is about one-fifth of that spent working in coal. That agrees very well with our own observation, and we have thought it safe to assume that by adding to the average of the ripping samples five times that of the samples taken when coal was being handled, and dividing the sum by six, an average fairly representative of coalface working in the absence of shot-firing is obtained. The ratio is not critical, for if, instead of taking weights of 5 to 1, we take 10 to 1 or $2\frac{1}{2}$ to 1 the results are not very seriously altered. For an average for coalface work, including the effects of shot-firing, we have allowed weights of 2 coal shot samples and 1 of roof shots to 20 coal-handling and 4 ripping samples. If these weights for shots are halved or doubled, still in the proportion of 2 coal shots to 1 roof shot, the effect on the average is not great.

The standard deviation of all the 40 observations made at this colliery, or the 28 observations excluding those made after shots had been fired, cannot

* The *standard deviation* is a measure of the scatter of a set of observations about their mean. It is the square root of the arithmetical average of the squares of the differences between the individual observations and the mean.

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be used to indicate the variability about the weighted means given in the Table. Instead, for each group of observations, i.e., those relating to coal-handling, to ripping, to coal shots and to roof shots, we have determined the root-mean-square deviation from the weighted mean, and have then applied the weights used in calculating the average, in order to arrive at the numbers given as the standard deviations in the table. The numbers of samples shown in brackets (27 and 24) are the numbers of units taken in calculating the weighted means. These numbers have been used in estimating the standard errors of the means for the purpose of the comparisons given later in Table XXIII; they are smaller than the actual numbers of observations, and we think it can be assumed that they do not, at any rate, cause those errors to be underestimated. On the other hand, the errors are probably not seriously magnified by this procedure.

TABLE XXIII

Differences (and their standard errors) between the average total dust counts at the coalface at various collieries (including samples taken after shot-firing)

Colliery.	No. of particles per c.c.	A.1.	A.3.	A.8.	A.2.
		4,302.	3,829.	4,310.	2,813.
A.1	4,302	—	—	—	—
A.3	3,829	473 ± 657	—	—	—
A.8	4,310	8 ± 563	481 ± 505	—	—
A.2	2,813	1,489 ± 530	1,016 ± 467	1,497 ± 324	—
B.3	2,164	2,138 ± 503	1,665 ± 437	2,146 ± 277	649 ± 201

The individual dust counts from which the averages shown in Table XXII have been derived varied greatly, as is shown by the large standard deviations; and before any importance can be attached to the differences between the averages it is necessary to consider their statistical significance. For the series of averages shown in the left-hand half of the table, i.e., those in which allowance is made for the effect of shot-firing, the differences between the various pairs of means, and the standard errors of those differences, are given in Table XXIII. Those differences which are at least twice as large as their standard errors, and which can therefore be presumed to be statistically significant, are shown in heavy type.

The average counts observed at Collieries A.1 and A.8 are almost identical, and higher than those for any other colliery. The average shown for Colliery A.3 is less than those for Collieries A.1 and A.8, but from Table XXIII it can be seen that it is not significantly less. At both Collieries A.2 and B.3 the average total counts are significantly lower than at the other three collieries, and the average for B.3 is significantly less than that for A.2.

Relating these results to the observed incidences of X-ray abnormalities in the lungs of the miners, it can be seen that the colliery with the lowest incidence (B.3) had significantly the lowest total dust count; at the colliery with the next lowest incidence (A.2) the average dust count was higher, and at the three collieries where the incidences were highest the observed average dust counts were significantly higher than at the other two collieries, but the averages for these three did not differ significantly from each other. When allowance is made for the fact, already stressed, that the dust concentrations recorded for Collieries A.1 and A.3 substantially underestimate the hazard of earlier years, it can safely be assumed that the dustiness over the period when the men were contracting their disability was significantly greater at these two collieries than at Colliery A.8. Thus it appears that, within the group of five mines, there is a distinct relationship between the incidence of

X-ray abnormalities and the concentration of air-borne dust as indicated by the total particle count derived from the thermal precipitator. The higher incidences are associated with the higher dust counts.

(b) *The numbers of particles of coal and of other minerals*

In the evaluation of the dust samples the particles of coal and of other minerals of 0.4 micron or greater size were counted separately, and the average numerical concentrations of these particles are shown in Table XXIV. The differences between the average numbers of particles of coal per c.c. and the standard errors of the differences are shown in Table XXV, and similar data for the particles of minerals other than coal are given in Table XXVI.

TABLE XXIV

Average numbers of particles of coal and of other minerals per c.c., of 0.4 micron or greater size, at the coalface at various collieries

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	All samples.			Excluding samples taken immediately after shot-firing.		
		No. of samples.	No. of particles per c.c. of		No. of samples.	No. of particles per c.c. of	
			Coal.	Other minerals.		Coal.	Other minerals.
A.1	233	(27)	2,484	788	(24)	2,328	643
A.3	172	23	2,434	332	20	2,236	232
A.8	146	42	2,863	615	42	2,863	615
A.2	12	56	1,750	332	53	1,721	307
B.3	4	118	859	396	118	859	396

TABLE XXV

Differences (and their standard errors) between the average numbers of particles of coal per c.c. of 0.4 micron or greater size at the coalface at various collieries (including samples taken immediately after shot-firing)

Colliery.	No. of coal particles per c.c.	A.1.	A.3.	A.8.	A.2.
		2,484.	2,434.	2,863.	1,750.
A.1	2,484	—	—	—	—
A.3	2,434	50 ± 369	—	—	—
A.8	2,863	379 ± 347	429 ± 323	—	—
A.2	1,750	784 ± 302	684 ± 274	1,113 ± 244	—
B.3	859	1,625 ± 278	1,575 ± 247	2,004 ± 213	891 ± 127

TABLE XXVI

Differences (and their standard errors) between the average numbers of particles of minerals other than coal per c.c. of 0.4 micron or greater size at the coalface at various collieries (including samples taken immediately after shot-firing)

Colliery.	No. of non-coal particles per c.c.	A.1.	A.3.	A.8.	A.2.
		788.	332.	615.	332.
A.1	788	—	—	—	—
A.3	332	456 ± 193	—	—	—
A.8	615	173 ± 163	283 ± 115	—	—
A.2	332	456 ± 162	0 ± 113	283 ± 45	—
B.3	396	392 ± 160	64 ± 111	219 ± 39	64 ± 34

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The comparison of the average counts of coal particles at the various collieries yields the same results as have just been described for the total dust counts. The averages for Collieries A.1, A.3 and A.8 do not differ significantly from each other, and each of these averages is larger than those for the other two collieries. The average for the lowest-incidence mine (B.3) is significantly less than that for any other colliery in the group.

Turning now to the numbers of particles of minerals other than coal, it is found that the highest average count occurred at Colliery A.1, where the incidence of X-ray abnormalities amongst the miners was highest. This average does not differ significantly from that recorded for Colliery A.8, which is third in order of incidence, but it will be remembered that the count at Colliery A.1 underestimated the former hazard. The average count of non-coal particles shown for Colliery A.3 is identical with that for the low-incidence mine, A.2, and does not differ significantly from that for Colliery B.3. It is certain, however, that the count at Colliery A.3 was formerly substantially higher than that shown, and it is not unreasonable to suppose that it was little if any less than those for Collieries A.1 and A.8. The average count of non-coal particles for the lowest-incidence mine, B.3, is slightly higher, though insignificantly so, than that for Colliery A.2. It will be remembered that at Colliery B.3, a bituminous mine, routine stone-dusting was performed for the prevention of coal-dust explosions, and the concentration of particles other than coal was undoubtedly influenced by that procedure.

It seems clear that there is some relation between the incidence in the workers of pulmonary abnormalities, as discovered by X-ray examination, and the dust concentration, as indicated by particle counts. The total particle count and the count of particles of coal were highest where the incidence of abnormalities was high. In the case of minerals other than coal, too, when allowance is made for the changed conditions at Colliery A.3, there appears to be a similar correlation between particle count and the incidence of pulmonary disease.

3. The size distribution of dust particles

For each colliery the average size distribution of the particles in the whole dust is given in Table XXVII, and the average median particle size is also shown.

TABLE XXVII

Average size distributions of particles in the whole dust at various collieries (including samples taken immediately after shot-firing)

Particle size (microns).	Average No. of particles of stated size as percentage of average total count at colliery.				
	A.1.	A.3.	A.8.	A.2.	B.3.
Under 0.2	9.4	10.4	8.0	10.0	21.1
0.2 to 0.4	14.5	17.4	11.3	16.0	20.9
0.4 to 0.8	17.3	24.0	12.8	19.5	16.7
0.8 to 1.2	12.8	14.8	11.6	13.7	10.6
1.2 to 1.6	10.6	8.8	11.2	9.3	7.6
1.6 to 2.0	8.3	5.3	9.4	7.4	5.5
2.0 to 2.5	6.3	4.8	8.4	5.5	4.8
2.5 to 3.0	6.1	3.7	8.0	4.8	4.1
3.0 to 4.0	6.7	4.0	8.1	5.8	3.9
4.0 to 5.0	5.5	3.8	6.9	5.2	3.3
Over 5.0	2.5	3.0	4.3	2.8	1.5
All sizes	100.0	100.0	100.0	100.0	100.0
Average medium particle size in microns, (i.e., average of median values for individual samples).	1.06	0.89	1.40	1.03	0.66

The percentage size distribution for Collieries A.1, A.3 and A.2 are very similar, and the small differences between the average median particle sizes are insignificant. At Colliery A.8 the proportion of small particles—e.g., those below 2 microns in size—differed from the proportions at the other mines; while, of all the five mines, the bituminous colliery B.3 had the greatest proportion of small particles and the least of large. These differences are reflected in the average median particle sizes, which were 1.40 micron at Colliery A.8, 0.66 micron at Colliery B.3 and from 0.89 to 1.06 micron at the other three collieries. In spite of the wide variations between the size distributions of individual samples, the average median particle sizes for Collieries A.8 and B.3 each differ significantly from those for the other collieries, and they differ significantly from each other.

The variability of the size distributions of the particles in individual samples is well illustrated by Table XXVIII, which records the frequency of occurrence of samples in which various percentages of the total numbers of particles were accounted for by particles smaller than 0.8 micron. The figures given for Colliery A.1 relate to all samples taken at the coalface. On the average, about half the dust particles were below 0.8 micron in size; but in individual samples the proportion of the small particles varied from under 20 per cent. to over 80 per cent. of the total count.

The particle size distributions of the whole dust appear to be unrelated to the incidence of pulmonary X-ray abnormalities, for amongst the four anthracite collieries here considered the particle sizes for the mines with the highest and lowest incidences are almost identical.

TABLE XXVIII

Frequency of occurrence of samples, taken at the coalface, in which various percentages of the total numbers of dust particles were below 0.8 micron in size

Colliery.	No. of samples.	No. of samples in which the number of particles smaller than 0.8 micron expressed as a percentage of the count total was:—					Average percentage below 0.8 micron.
		under 20.	20 to 39.9.	40 to 59.9.	60 to 79.9.	80 and over.	
A.1 ..	40	—	9	27	4	—	46.2
A.3 ..	23	—	8	8	6	1	50.7
A.8 ..	42	1	33	8	—	—	32.5
A.2 ..	56	1	28	12	14	1	45.5
B.3 ..	118	—	5	68	44	1	57.5

The average percentage size distributions of the coal and other particles are shown separately in Table XXIX. Among the coal particles, especially, there are substantial variations between the proportions of small particles found at the different mines. The size distributions of the particles of minerals other than coal were found to be very similar at the four anthracite mines. At Colliery B.3 the proportionate numbers of the smallest particles were less than in the anthracite mines, probably owing to stone-dusting. In the case of the four anthracite mines, there appears to be no relation between the incidence of pulmonary X-ray abnormalities and the percentage size distributions of the two fractions of the dust.

4. The mass concentration of the dust

Estimates of the mass concentration of the dust, computed from the average particle counts and size distributions, are recorded in Table XXX. Since the discrimination of the two fractions of the dust was not carried below 0.4 micron, the mass concentrations are calculated for particles exceeding

TABLE XXIX

Average percentage size distributions of particles of coal and of other minerals at various collieries

Colliery.	No. of samples.	Coal particles.							Particles of minerals other than coal.						
		Average number per c.c.	Percentage of size (microns) :—						Average number per c.c.	Percentage of size (microns) :—					
			0.4-1.2.	1.2-2.0.	2.0-3.0.	3.0-5.0.	5.0 and over.	Total above 0.4.		0.4-1.2.	1.2-2.0.	2.0-3.0.	3.0-5.0.	5.0 and over.	Total above 0.4.
A.1	(27)	2,484	29.3	27.6	19.1	19.8	4.2	100.0	788	72.2	16.0	7.4	4.1	0.3	100.0
A.3	23	2,434	50.8	20.7	12.2	11.7	4.6	100.0	332	74.8	10.8	8.4	5.1	0.9	100.0
A.8	42	2,863	20.7	27.7	23.5	21.8	6.3	100.0	615	74.3	15.8	5.3	3.8	0.8	100.0
A.2	56	1,750	38.6	24.3	15.8	16.9	4.4	100.0	332	76.8	13.9	4.8	4.2	0.3	100.0
B.3	118	859	44.0	20.5	17.1	15.1	3.3	100.0	396	53.8	27.0	12.1	6.3	0.8	100.0

TABLE XXX

Estimated average mass concentrations of air-borne dust at the coalface at various collieries

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	Estimated average mass concentrations (mg. per cub. metre) taking into account particles of size :—											
		greater than 0.4 micron.				0.4 to 10 microns.				0.4 to 5.0 microns.			
		Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.	Coal.	Other minerals.	Total.	Other minerals as percentage of total.
A.1	233	93.4	6.1	99.5	6.1	61.3	6.1	67.4	9.1	32.3	5.0	37.3	13.4
A.3	172	223.6	7.3	230.9	3.2	61.8	3.8	65.6	5.8	19.9	2.3	22.2	10.4
A.8	146	158.6	7.5	166.1	4.5	97.5	5.9	103.4	5.7	39.9	3.3	43.2	7.6
A.2	12	79.8	2.4	82.2	2.9	47.3	2.4	49.7	4.8	19.7	1.8	21.5	8.4
B.3	4	18.7	4.8	23.5	20.4	16.3	4.8	21.1	22.7	8.3	3.7	12.0	30.8

that size. It can be shown, however, that if the particles below 0.4 micron in size had been included the mass concentrations would not have been sensibly influenced; the maximum effect would have been to increase the total concentration by 0.1 mg. per cub. metre. Estimates are given of the mass of all particles larger than 0.4 micron, of particles not exceeding 10 microns in size, and of particles up to 5 microns.

When all particles larger than 0.4 micron are included, the estimates of mass concentration vary greatly. The differences are caused by variations in the proportions of large coal particles at the different collieries. The numerical proportions of coal particles larger than 5 microns, shown in Table XXIX, range from 3.3 per cent. of the total at Colliery B.3 to 6.3 per cent. at Colliery A.8, but these percentages give no indication of the actual sizes of the particles. The maximum coal particle size observed at Collieries B.3 and A.8 was 20 microns, and in narrow places at Colliery A.3 the sizes of the particles ranged up to 30 microns. In the samples from longwall stalls at Colliery A.3 (not included in the present comparison), particles as large as 50 microns were seen. It is doubtful, however, whether much of the dust of these large sizes has any pathological significance, and no stress is laid on this part of the Table.

The mass concentrations of particles not exceeding 10 microns in size probably give a better representation of the concentrations of dust which can gain access to the depths of the lungs, but in the light of the investigations quoted earlier in this report it would appear that the mass concentrations of the particles not exceeding 5 microns in size give a better measure of the hazard to health, and our discussion will be confined to these estimates.

From Table XXIX it will have been noticed that only a minute proportion of the non-coal particles exceeded 5 microns in size. Consequently, as the upper limit of particle size included in the estimates of mass concentration is lowered, the proportion of minerals other than coal is increased; thus, at Colliery A.3, when all particles greater than 0.4 micron are included the non-coal fraction represents only 3.2 per cent. of the whole, but when the estimates are based on particles not exceeding 5 microns the percentage is raised to 10.4.

Comparing the masses of coal particles not exceeding 5 microns in size, it is seen that the lowest-incidence mine, B.3, had easily the lowest concentration of coal dust, viz., 8.3 mg. per cub. metre. At Colliery A.2, where the incidence was also low, the concentration was 19.7 mg. per cub. metre. At Colliery A.8, where the incidence was much higher than at A.2, this figure was doubled, for the concentration was 39.9 mg. The concentrations estimated for the still higher incidence mines, A.1 and A.3, are lower than that found at Colliery A.8. The concentrations at Collieries A.1 and A.3 were, however, formerly substantially higher than those measured by us, and it is safe to assume that the earlier dust concentrations at these collieries were both at least as high as that recorded for Colliery A.8.

The concentration of minerals other than coal at the bituminous mine, B.3, was influenced by the routine stone-dusting. The effect of the use of limestone dust for this purpose on the chemical composition of the air-borne dust is discussed by Nagelschmidt (p. 111). We are unable from our data to say what proportion of the minerals other than coal represented the limestone used for stone-dusting, but it must have been substantial, and we cannot therefore use the data for this colliery in considering the relation between the incidence of pulmonary disease and the concentration of minerals other than coal. Taking the figures for the four anthracite mines, it does appear that the incidence of X-ray abnormalities is related to the concentration of these minerals. Of the four mines, that with the lowest incidence of abnormalities, A.2, had the lowest concentration of minerals other than coal. Colliery A.1, where the incidence was highest, had the highest concentration, and it will be

TABLE XXXI

Estimated average surface areas of air-borne dust at the coalface at various collieries

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	Estimated surface areas (sq. mm. per litre) taking into account particles of size :—								
		greater than 0.4 micron.			0.4 to 10 microns.			0.4 to 5 microns.		
		Coal.	Other minerals.	Total.	Coal.	Other minerals.	Total.	Coal.	Other minerals.	Total.
A.1	233	63.8	5.1	68.9	56.4	5.1	61.5	40.9	4.7	45.6
A.3	172	79.6	3.0	82.6	45.3	2.5	47.8	26.5	2.0	28.5
A.8	146	97.5	4.3	101.8	82.5	4.1	86.6	52.3	3.3	55.6
A.2	12	46.2	2.0	48.2	38.4	2.0	40.4	25.0	1.8	26.8
B.3	4	16.7	3.8	20.5	16.0	3.8	19.8	11.5	3.4	14.9

remembered that the recorded figure is an underestimate. The relatively low figure shown for Colliery A.3 is also an underestimate, and the concentration which prevailed in former years must have been at least as high as that shown for Colliery A.8.

5. The surface area of the dust

Finally, in this comparison of the collieries, Table XXXI shows the estimates of the surface area of the dust expressed as sq. mm. per litre. The relations between the incidence of pulmonary X-ray abnormalities and the surface areas of the two fractions of the dust are very similar to those between incidence and mass concentration, and it is unnecessary to describe them in detail. Bearing in mind the changed conditions at Collieries A.1 and A.3, and the fact that the surface area of the non-coal fraction of the dust at Colliery B.3 is affected by the process of stone-dusting, it can be seen that the surface area of the dust in unit volume of the dust cloud increased with the increasing incidence of pulmonary disease in the miners.

6. Discussion

(a) Total dust

From the comparisons made in the preceding pages, it appears that, when allowance is made for the changes which have taken place at Collieries A.1 and A.3, there is some degree of correlation between dust concentrations and the incidence of pulmonary X-ray abnormalities in the miners. The mass concentrations of dust particles up to and including 5 microns in size are greater at the collieries with a high incidence of abnormalities than at those where the incidence is low.

In the Pennsylvania investigation also (Bloomfield *et al.*, 1936), it appeared that the incidence of anthraco-silicosis was related to the concentration of the total dust. The coalface workers were exposed to dust containing less than 5 per cent. of free silica, and amongst those workers, with a given period of exposure, the incidence of disease increased as the dust concentration increased, while, with a given degree of dustiness, the incidence increased with increasing length of exposure.

It is difficult to compare the American results with those obtained in the present investigation, on account of the different methods employed for estimating dust concentrations: the American dust concentrations are expressed in terms of the particle counts derived from impinger samples, and these are not directly comparable with the counts obtained by us from thermal precipitator samples. It may, however, be permissible to attempt an approximate comparison. Bloomfield and Dalla Valle (1935) found a good degree of correlation ($r = 0.77$) between impinger counts and gravimetric estimations of the mass concentration of dust in the air of anthracite mines, and they found that 1 mg. of the dust represented about 44 million particles. We are not certain that this relation holds strictly for the data in the Pennsylvania report, but we have ventured to apply it to those figures, for the purpose of estimating the mass concentrations of dust found in the survey there described. In the Pennsylvania inquiry comparatively little attention was paid to the particle size of the dust, for only 1,500 particles were measured altogether, and less than 1,000 of these represented the dust at the coalface. All the particles measured were, however, less than 4 microns in size, and, in attempting a comparison of the mass concentrations observed in the two investigations, it seems obvious that the American data should be compared with our estimates of the mass concentrations of particles not exceeding 5 microns in size.

In the American study no cases of anthraco-silicosis were found when the dust count was below 5 million particles per cubic foot (or 177 per c.c.). This figure can be calculated to represent a mass concentration of about 4 mg. per

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cub. metre, a concentration only one-third of the lowest average observed by us, namely that for our low-incidence colliery, B.3, for particles not exceeding 5 microns in size.

At the coalface in the Pennsylvania mines the average dust concentration to which the workers were exposed was almost invariably at least 100 million particles per cubic foot (3,530 per c.c.), or 80 mg. per cub. metre; and 290 of the 426 coalface workers examined were exposed to average concentrations exceeding 300 million particles per cubic foot (10,590 per c.c.), or 240 mg. per cub. metre. The highest mass concentration of the total dust shown in Table XXX, taking into account only particles up to 5 microns in size, is the 43 mg. per cub. metre estimated for Colliery A.8, although it is likely that in former years the concentration at Colliery A.1 exceeded that figure. It appears that, so far as dust of respirable size is concerned, the Pennsylvania mines were considerably more dusty than the Welsh mines included in the present investigation.

In bituminous mines in Utah, too, the incidence of pneumokoniosis amongst the miners increased with increased weighted average dust concentrations and increasing durations of employment (Flinn *et al.*, 1941). No case was found that presented the typical picture of well-advanced anthraco-silicosis seen amongst anthracite miners, and the absence of such cases is ascribed to the considerably lower dust exposures in the bituminous mines. The weighted average dust exposures, again as evaluated from impinger samples, for various types of coal face workers in the bituminous mines vary from 7.8 to 38.2 million particles per cub. ft. (275 to 1,350 particles per c.c.); whereas in the anthracite mines of Pennsylvania practically all the coalface workers examined were exposed to concentrations of at least 100 million particles (3,530 particles per c.c.), and a large proportion of them were exposed to concentrations of 300 million particles or more per cub. ft.

From Table XXX it would seem that the correlation between the incidence of radiographic abnormalities and the concentration of dust of respirable size (i.e. up to 5 microns) holds for both fractions of the dust, the coal and the minerals other than coal; and from our data it cannot be said that either fraction of the dust may be regarded as harmless. From the figures given in the table, however, it may perhaps be thought that, within the group of anthracite collieries, where no complication is caused by stone-dusting, the incidence of X-ray abnormalities is related more closely to the concentration of minerals other than coal than to the concentration of coal dust; for at the highest-incidence mines, A.1 and A.3, the minerals other than coal formed a larger percentage of the total dust than at the other collieries.

Even if the data which have been adduced do not enable us to point with assurance to either fraction of the dust as that to which the pulmonary troubles of the miners are attributable, they do lead clearly to a conclusion of great practical importance—namely, that, since high incidences of pneumokoniosis are associated with exposure to excessive dust concentrations, every effort must be made to reduce the dustiness in anthracite mines if the disease is to be brought under control.

It would have been a highly satisfactory conclusion to this investigation if we had been able to indicate with assurance the maximum dust concentrations which could be considered to represent safe working conditions. A clear and indisputable specification of such concentrations cannot be made from the data at our disposal, but we think that it is possible to indicate concentrations which might well be adopted as provisional standards, the maintenance of which would be likely to have a profound influence on the health of the miners.

(b) Coal dust

We may first consider the concentration of the coal fraction of the dust. The data at our disposal do not enable us to acquit this fraction of responsibility

for the pulmonary disease incurred by the miners. It cannot be asserted that the coal dust is responsible for the disease, but equally it cannot be said that it is innocuous. At Colliery A.2, where the incidence of X-ray abnormalities was low, the concentration of coal dust of Mavrogordato's "silicosis-producing" size, viz., not exceeding 5 microns, was about 20 mg. per cub. metre, and at Colliery B.3, where the incidence was still lower, it was about 8 mg. It seems clear, therefore, that every endeavour should be made to ensure that the concentration of coal dust of sizes up to and including 5 microns does not exceed 20 mg. per cub. metre, and we suggest that it should preferably not exceed 10 mg.

(c) *Minerals other than coal*

In Table XXX it is shown that at Colliery A.2, a low-incidence anthracite mine, the average concentration of minerals other than coal not exceeding 5 microns in size was 1.8 mg. per cub. metre. Of the 40 men examined after employment at this colliery for from 10 to 20 years, 5 per cent. showed abnormalities of the "consolidation" type, while of the 28 men who had been employed for over 20 years none showed consolidation. It seems clear that the concentration of minerals other than coal in the air-borne dust of anthracite mines should at least be reduced to that observed at Colliery A.2. A further reduction in the concentration of this fraction of the dust should be aimed at, for such a reduction could be expected to bring about a further diminution in the incidence of pneumokoniosis. We suggest that every effort should be made to ensure that, in the air of anthracite mines, the concentration of particles of minerals other than coal not larger than 5 microns in size, does not exceed 1 mg. per cub. metre.

The suggestion that the incidence of pulmonary changes among the miners of South Wales can be related to the concentration of minerals other than coal in the air of the mines is directly opposed to certain views which have been put forward by other writers.

Haldane (1931) considered that there was no evidence to show that any class of work in coalmining was subject to risk from silicosis except in rare cases; he also thought there was no clear evidence that dust inhalation by coalminers was an ordinary cause of either bronchitis or pneumonia among them, although excessive inhalation of coal dust or shale dust might cause bronchitis and ought therefore to be avoided. He attributed the high incidence of what was then believed to be bronchitis among the older miners to the severe muscular work performed by them over many years. In the discussion on Haldane's paper, Collis threw doubt on the muscular-exertion theory of bronchitis among coalminers, and remarked that the facts seemed to reinforce Haldane's final conclusion that "it seems practically certain that excessive inhalation of coal dust or shale dust must cause bronchitis, and ought therefore to be avoided".

T. D. Jones (1936) refers to the "alleged silicosis" of anthracite miners and affirms that "the apparent harm attributed to the dust in anthracite mines is, in reality, dependent on bronchitis resulting from exposure to cold on the spades, with secondary accumulation of coal dust in the lungs in consequence of the normal process of elimination of dust from the lungs being paralysed".

In a paper published after Dr. Haldane's death, Haldane, Haynes, Shaw and Graham (1939) expressed the view that the term silicosis should be applied only to the fibrotic condition of the lungs found in persons with a history of exposure to dust containing a high proportion (about 50 per cent. or more) of free silica; and they appear to accept the opinion that the pulmonary disability suffered by anthracite miners is really due to bronchitis, possibly aggravated by the accumulation of dust in the lungs.

The relation of chilling to the incidence of pulmonary abnormalities will be discussed in the part of this report which deals with the thermal conditions in the mines (p. 68). Here we are concerned with the relation between those

abnormalities and dust. It is outside our province to argue whether or not the pulmonary disease of coalminers should be called silicosis, and from our standpoint it is immaterial what name be given to the condition. The point at issue here is whether the inhalation of dust is the main cause of the disability. We conclude that it is.

PRACTICAL SUGGESTIONS

1. *Standards of Permissible Dustiness*

We suggest that, if standards of the maximum permissible dustiness at the coalface in anthracite mines are set up, they should be based on the mass concentration of dust not exceeding 5 microns in size. We are in some doubt as to what concentrations should reasonably be taken as the basis of provisional standards for immediate practical application, but we are of opinion that the goal to be aimed at is a maximum concentration of 1.0 mg. of minerals other than coal per cub. metre, with the coal dust not exceeding 10.0 mg., both those figures referring to particles 5 microns or less in size. Standards of maximum permissible dustiness in terms of the mass of dust of a restricted range of particle size would cause administrative difficulties, for such concentrations cannot be determined directly by gravimetric methods. It would be necessary to compute the mass concentrations from particle counts and size distributions as we have done, and that is a laborious procedure.

We propose, therefore, that the standards be expressed in terms of the numerical concentrations of dust particles. Earlier in this report (p. 13) we have shown that in anthracite mines there is a close relationship between the mass concentration of the dust not exceeding 5 microns in size and the numerical concentration of particles not less than 1 micron in size. It may be calculated from the equations given on page 13 that a concentration of 10 mg. per cub. metre of coal dust not exceeding 5 microns in size corresponds to 667 coal particles of not less than 1 micron diameter in each c.c. of the dust cloud, and that similarly 1 mg. per cub. metre of dust of minerals other than coal represents a count of 59 particles of at least 1 micron diameter in each c.c. We suggest that round figures be taken, and that the maximum permissible concentration of coal dust not less than 1 micron in size be fixed at 700 particles per c.c., and that the corresponding concentration of dust of minerals other than coal be fixed at 60 particles per c.c. We realise that the attainment of the suggested standards will not be easy, but we urge that every effort should be made to reduce the general level of dustiness to that proposed.

We also suggest that the thermal precipitator be used as the standard sampling instrument, and that the evaluation of the samples under the microscope be done with a 2 mm. oil-immersion objective and a $\times 15$ to $\times 20$ eyepiece. For routine dust control work, mining engineers will probably prefer some other instrument, e.g., the konimeter or the jet dust counter, to the thermal precipitator, since either of these is more convenient than the thermal precipitator for use underground. Before these or other instruments can be used in place of the thermal precipitator for dust control work on the basis of the suggested standards, however, it will be necessary to investigate, in anthracite mines, the relative sampling efficiencies of the instruments which it is proposed to employ. It will be necessary to determine, for a long series of samples taken under various conditions, how accurately the counts given by the thermal precipitator technique can be predicted from counts yielded by these other instruments. We suggest that an investigation of the sampling efficiencies of various instruments be undertaken as soon as possible. In our view the thermal precipitator should be retained as the standard instrument of reference in case of dispute.

2. *Dust Control Measures*

Dust control can be exerted by preventing the formation of dust, by preventing the dispersion of the dust when formed, and by the rapid removal of dust when dispersed. Each of these methods may be employed in the control

of dust in anthracite mines, and below we venture to make certain suggestions as to the measures which, in our view, can be applied.

(a) *Control of shot-firing*

We suggest that as far as possible no shot-firing, either in coal or in stone, should be done on coal-getting shifts, so as to restrict the number of men who are exposed to the increased dust concentrations caused by blasting.

If shots must be fired during coal-producing shifts, measures should be taken to ensure that the miners are exposed as little as possible to the increased dust concentrations. Even on well-ventilated longwall faces they should not return to work until at least ten minutes after shots have been fired, and where the ventilation is less good this period should be increased. In headings, where there is no through ventilation, the use of mist projectors would do much to suppress the dust caused by blasting, and would thus make possible an earlier resumption of work in relatively safe conditions.

(b) *General tidiness*

We have already suggested that if, after ripping, all the rippings were disposed of as completely as possible, so that no dirt was left lying about to be again disturbed during the shovelling of coal, a reduction in the amount of dust composed of minerals other than coal might be effected.

We suggest that greater attention be paid to general tidiness at the coalface, thus practising the doctrine of good housekeeping, upon which so much stress is now laid in connection with dust control in other industries.

(c) *Ripping*

It might help towards this end if all the processes of ripping were done on a non-coal-getting shift. The men employed on this work could be made responsible for clearing away all rippings.

(d) *Wetting of coal and rippings before loading or stowage*

It has been shown that great reductions in dust concentrations can be brought about by the spraying with water of all material before it is loaded or stowed.

We suggest that this practice be adopted wherever possible. Immediately after coal has been got from the face, or rippings brought down from the roof, the material should be well sprayed and, if possible, left for some time before being loaded or stowed, so that the water has time to permeate the mass and thus prevent the dispersion of dust in subsequent loading. If water is laid on to the face, and compressed air is available, the spraying will present no difficulty. In any case, it should be a relatively simple matter for water tanks to be distributed to the districts, so that the water can be applied by means of watering-cans or even with the aid of the stirrup-pump now used for fire-fighting. Our experiments show that this procedure effects a substantial reduction of the dust concentrations with a water consumption of 3 to 5 gallons per hour in each working place.

(e) *Allaying of dust in roadways*

We suggest that water sprays, preferably in the form of mist projectors, be used for the laying of dust in mine roadways.

(f) *Ventilation*

An obvious way in which dust concentrations can be reduced is by increased ventilation. Even if the dust production remains constant, an increase in the volume of air passing means that the dust is mixed with a greater volume of air, and its concentration thus reduced.

We therefore suggest that every practicable step be taken to ensure the best possible ventilation at the coalface. Care should be taken to discover and prevent any of the leakages by which much of the air handled by the colliery fan is so frequently prevented from reaching the face. Large airways should be maintained and every effort made to keep down resistance to the flow of air. Where practicable, longwall working should be adopted in preference to narrow working, and the longwall faces should be well maintained and well-aligned,

so that the ventilating current thoroughly scours each working place. In any necessary headings care should be taken to secure the best possible ventilation by bratticing or other means.

In the past, probably the greatest stimulus to increased effort in the improvement of mine ventilation has been the need for the removal of firedamp. We learn that, in his campaign for a reduction of the dust concentrations in the mines under his control, the agent for one group of anthracite mines has instructed his subordinate officials to treat dust as gas. Such a policy applied intelligently and energetically should have valuable results.

SUMMARY

1. Certain present-day methods of dust sampling are briefly described, and the methods of dust counting compared. It is concluded that, of the instruments at present available, the thermal precipitator is the most suitable for use in a study where the fullest possible information about the dust is desired.

2. From the results of recent research it appears that small dust particles are more injurious than large ones. There is a consensus of opinion that particles larger than 5 microns are of little pathological significance, while some workers suggest that particles larger than 3 microns are of little account.

Industrial dust concentrations are commonly measured in terms of the number of dust particles present in unit volume of air, and the dust count obtained for a given dust cloud depends on the sampling method and counting technique employed. A more exact method of expression would appear to be the mass concentration below a stated size, say 5 microns, or perhaps the surface area presented by the dust in unit volume of the dust cloud.

How far the mass concentrations for such a limited range of particle size, or the surface area, can be predicted from the particle count is discussed in the light of the results of a statistical study. The correlation of total particle counts with total mass concentrations is lower than the similar correlations reported by American observers, the difference being due largely to the different methods of dust sampling and microscopic examination employed. In the case of coalmine dust a high correlation was found between the count of particles above 1 micron in size and the mass concentration of particles not exceeding 5 microns in size. This finding supports the view held in the United States, that the impinger method of dust sampling provides a useful means of estimating the silicosis risk.

The relatively low correlation between the total mass concentration and the mass of particles up to 5 microns in diameter only, raises doubt whether in coalmining direct gravimetric observations of the mass concentrations of dust are of much hygienic significance.

3. In the field investigation described in this report sampling was done by means of the thermal precipitator, and the technique used has been described. Particles of coal and of other minerals were visually discriminated down to 0.4 micron diameter. Separate counts and size distributions are given for these two fractions of the dust. From the average particle counts and size distributions for groups of observations, estimates have been made of the mass concentration and the surface area of the dust per unit volume, not only for the total dust but also for various ranges of particle size. Dust surveys were made at four anthracite mines and at one bituminous mine. The anthracite mines included three at which high or fairly high incidences of X-ray abnormalities in the lungs of the miners had been observed by the medical investigators, and one where the incidence was low. The incidence of such abnormalities at the bituminous mine was also low.

4. In the course of the dust surveys, information illustrating the effects of various factors on the amount and nature of the dust at the coalface was obtained.

Comparing the dust concentrations in longwall stalls and in narrow places at the same colliery, it was found that the total dust count was 75 per cent. higher in the narrow places than on the longwall faces; the numbers of particles of dust other than coal were similar, and the excess was due to more numerous coal particles in the narrow places. The mass concentration of all the dust of presumably harmful size, i.e., 5 microns or smaller, was nearly 40 per cent. more in the narrow places than in the stalls. There were only a few narrow places at this colliery, and the dust concentrations observed in them were certainly far lower than would have been found in a colliery worked entirely on the narrow method.

At another colliery with longwall working the dust concentrations in stalls and topholes were compared. It appears that longwall faces worked as stalls or on the tophole system are about equally dusty, while there is distinctly more dust at the loading ends of topholes than at the face.

Observations showing the increased dustiness consequent on shot-firing are described, and the effect of the ventilating current in removing the dust caused by blasting is illustrated. It is concluded that on a longwall face with good ventilation the miners would avoid inhaling much harmful dust if they retired from the air current for at least ten minutes after the firing of shots; in worse ventilated places a longer retirement would be desirable.

Dust concentrations are much influenced by the nature of the operations being performed. Illustrations are given of the fluctuations in dustiness that occur in the same working place. A comparison has been made of the dust concentrations prevalent during coal-handling and during ripping. The concentrations of minerals other than coal were about the same for the two kinds of work, but the greater concentrations of coal dust were found during the handling of coal. A possible explanation of the presence of similar concentrations of minerals other than coal during the two operations seems to be that, even when no ripping was being done, there was generally a considerable amount of dirt lying about, and that this was disturbed when coal was shovelled. It is suggested that after ripping, all dirt should be disposed of as completely as possible, so as to reduce the amount of ripping dust present in the air during other operations.

Atmospheric humidity of itself appears to have no effect on dust concentration. Moisture affects dust concentrations in another way, however, for in localities where the rock surfaces were visibly wet low dust concentrations were found.

Dust reduction with the help of water is discussed. Observations are described which show the valuable effect of applying water to mine roadways, and experimental data indicate that striking reductions in the dust concentrations at the working face can be secured by spraying all material before it is loaded. It is suggested that spraying of all material at the coalface should be carried out wherever possible.

5. The average dust concentrations at the coalface at the various collieries have been compared with the incidences of radiographic pulmonary abnormalities at those collieries. When allowance is made for the changes in the working conditions at two of the collieries, it appears that—whether the concentration of the dust be measured in terms of the particle count, or of the mass concentration of the smaller and more harmful particles, or of the surface area of the dust per unit volume of the dust cloud—the concentration is related to the incidence of pulmonary X-ray abnormalities amongst the colliers. The higher incidences are associated with the higher dust concentrations. This relation holds for both fractions of the dust, and it cannot be said that either of the two fractions, the coal or the other minerals, is harmless. Clearly, the dust concentrations in anthracite mines must be reduced if pulmonary disease is to be brought under control. It is suggested that the concentration of coal dust not exceeding 5 microns in size should be not more than 10 mg. per cub.

metre, and that the concentration of dust of minerals other than coal of that size should not exceed 1 mg. per cub. metre.

6. Standards of maximum permissible dustiness in terms of the mass of dust of a restricted range of particle size would cause administrative difficulties. It is therefore proposed that any standards be set up in terms of the numerical concentration of dust particles not less than 1 micron in size, and it is suggested that, in anthracite mines, the maximum permissible concentrations should be 700 coal particles per c.c. of the dust cloud, and 60 particles of minerals other than coal per c.c.

It is further suggested that the thermal precipitator be used as the standard sampling instrument, and that in the evaluation of the samples under the microscope a magnification of 1,200 to 1,500 be used.

For routine dust control work, it may be desired to use more convenient instruments than the thermal precipitator. If such instruments are used it will be necessary to determine their sampling efficiencies for dust clouds such as are encountered in anthracite mines, and an early investigation of the comparative efficiencies of various dust-sampling instruments is desirable.

7. Various measures are suggested for dust control in coalmines. These include the relegation of shot-firing to non-coal-getting shifts as far as possible, or the enforcement of a waiting period of not less than 10 minutes before colliers return to the face after firing; the use of mist projectors to suppress the dust caused by blasting in headings; attention to general tidiness at the coalface; the spraying of all coal and rippings before loading or stowage; the allaying of dust in mine roadways; and increased attention to ventilation.

PART III.—A STUDY OF THE ATMOSPHERIC CONDITIONS IN CERTAIN MINES

INTRODUCTION

In discussions of the incidence of pulmonary disease among coalminers, and especially among anthracite miners, much importance has been attached to the occurrence of bronchitis. T. D. Jones (1935 and 1936), and Haldane, Haynes, Shaw and Graham (1939) have argued that the primary cause of the lung trouble with which this investigation is concerned is bronchitis caused by chilling.

Most of the anthracite mines in South Wales have no shafts, and access to them is by slants or inclined adits. Commonly the men ride to and from work for considerable distances, and the trains in which they are conveyed are known as "spakes". Sometimes the spake may consist of a train of the tubs or trams used for hauling coal, but in many collieries specially constructed trolleys, with wooden seats placed upon them at right angles to their length, are used. Usually the spake runs in the main intake airway and, especially when trolleys are used, the men are exposed to the chilling effect of a considerable wind as the spake approaches the surface. Moreover, in cold weather, they are exposed to a rapidly falling temperature as the spake travels outbye from the warm mine. Jones, and Haldane and his collaborators, attributed the pulmonary abnormalities of the miners to bronchitis contracted through this chilling.

In view of these claims, and of the clear possibility that thermal conditions might exert some influence on the incidence of respiratory infections in coalminers, a study of the thermal environment at the coalface, and of the degree of chilling experienced during transit to the surface, was indicated; and we have accordingly made surveys of the atmospheric conditions at the five mines at which our dust surveys were made, and at two additional anthracite mines, A.4 and A.7.

If the thermal environment is to be completely specified, one must take into account the temperature, humidity and velocity of the air, and also some measure of the radiation from the solid surroundings, e.g., the mean temperature of the surrounding surfaces. It has been shown by Lawton (1937) that there is generally only a very small difference between the temperature of the air and that of the exposed surfaces of the strata. That being so, the measurement of radiation can safely be omitted in considering underground conditions, for the dry bulb temperature of the air also indicates the temperature of the surfaces from which the men are receiving radiation. In the observations described in this report the dry bulb and wet bulb temperatures of the air were measured by the sling hygrometer, and the relative and absolute humidities subsequently ascertained by reference to appropriate tables. Air velocities were measured with a katathermometer or, where the velocity was high and uni-directional, as in mine roadways, with a vane-type anemometer or a velometer.

Since the effects of the thermal environment on the worker depend on a combination of factors, comparison of the conditions in different places is made easier by the use of an index of warmth which gives due weight to each of these factors. Such an index is provided by the scale of *effective temperature*, which takes into account the temperature, humidity and rate of movement of the air. The effective temperature of an environment connotes that temperature of still air, saturated with water vapour, in which an equivalent sensation of warmth was experienced by subjects in a series of tests made at the Pittsburgh Laboratory of the American Society of Heating and Ventilating Engineers. Scales of effective temperature are available for persons (a) stripped to the waist, and (b) normally clothed. In the mines included in this investigation we rarely if ever saw men stripped to the waist; they wore at least a thick singlet. We have therefore thought that the scale for clothed persons—which, after all, refers to light American clothing—is the more applicable to this survey. Accordingly, the effective temperatures given later are on the clothed scale.

Notes about the collieries examined were given in the first part of this report. Reference was made to certain changes that had occurred during the past twenty years or so, and it was shown that the dust hazard at certain mines was under-estimated by the data collected during our surveys. Regarding the thermal conditions, however, it was concluded that the only substantial effect of the changed conditions was that at Colliery A.3 the air velocities measured at the coalface during the survey were higher than the velocities which formerly prevailed. Generally speaking, the findings to be described give a fair representation of the atmospheric conditions at the various collieries for many years past.

THERMAL CONDITIONS AT THE COALFACE

Observations of the thermal conditions at the coalface were made in each seam and district of each mine. The numbers of observations made in each locality at a given colliery were roughly proportional to the numbers of workplaces, so that the simple averages of the results obtained fairly represent the average conditions at the colliery.

At all the mines except Collieries A.7 and B.3 observations were made in both winter and summer, but at these two collieries only winter observations were made. The temperatures observed during the summer differed only very slightly from those of the winter, and, since the seasonal temperature variations were so small, no serious error is involved in the assumption that the temperatures observed at Collieries A.7 and B.3 represent the average conditions for those collieries.

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TABLE XXXII

Average thermal conditions observed at the coalface in various collieries

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	Average thermal conditions						
		No. of observations.	Dry bulb temperature ° F.	Wet bulb temperature ° F.	Relative humidity per cent.	Absolute humidity as grains of water vapour per lb. of dry air.	Air velocity. Feet per minute.	Effective temperature. Clothed scale ° F
A.1	233	53	78.4	71.3	71	103	133	73.0
A.3	172	41	69.8	66.3	83	90	63	67.1
A.8	146	52	70.8	65.8	77	84	63	67.8
A.7	95	34	69.6	66.3	84	90	65	67.0
A.4	55	66	66.3	64.1	89	86	45	64.6
A.2	12	54	62.4	61.3	94	78	55	60.8
B.3	4	63	69.9	66.8	85	92	92	67.0

The average conditions observed at the coalface in the various collieries are recorded in Table XXXII. The highest temperatures were observed at Colliery A.1, where the dry bulb temperature averaged 78.4°F. and the average effective temperature was 73.0°F. At Collieries A.3, A.7, A.8 and B.3 the mean effective temperatures ranged only from 67.0° to 67.8°F., and the dry bulb temperatures from 69.8° to 70.8°F. Colliery A.4 was slightly cooler, with an average effective temperature of 64.6° and a dry bulb temperature of 66.3°F.; while the coolest conditions were observed at Colliery A.2, where the effective temperature was on the average only 60.8° and the dry bulb temperature 62.4°F.

The average relative humidities were roughly in inverse relationship to the average temperatures. The highest relative humidity (94 per cent.) was at Colliery A.2 and the lowest (71 per cent.) at Colliery A.1. On the other hand, the absolute humidity, expressed in the Table as the number of grains of water vapour associated with a pound of dry air, increased with increasing temperature.

The highest average air velocity was observed at Colliery A.1, and the next highest at Colliery B.3. At the remaining collieries the average velocities were very similar to each other.

TABLE XXXIII

Percentage frequency of occurrence of various dry bulb air temperatures at the coalface in certain collieries

Colliery.	No. of observations.	Mean temperature ° F.	Percentage of observations when temperature ° F. was :-						
			56 to 59.9.	60 to 63.9.	64 to 67.9.	68 to 71.9.	72 to 75.9.	76 to 79.9.	80 to 83.9.
A.1	53	78.4	—	—	—	8	19	28	45
A.3	41	69.8	2	5	20	51	15	7	—
A.8	52	70.8	—	2	19	31	46	2	—
A.7	34	69.6	—	6	32	24	38	—	—
A.4	66	66.3	1	21	50	26	2	—	—
A.2	54	62.4	26	41	29	4	—	—	—
B.3	63	69.9	—	5	29	36	22	8	—

It will be realised that amongst the individual observations there was considerable variation from the averages shown in Table XXXII. The extent of this variation in the case of air temperature is shown in Table XXXIII, which gives the percentage frequency of occurrence of various temperatures at the different collieries. The distributions of temperature at Collieries A.3,

A.7, A.8 and B.3 did not differ significantly from each other. At Colliery A.1 high temperatures were more frequent than at the four collieries just mentioned, and at Collieries A.2 and A.4 relatively low temperatures were more frequently encountered. The χ^2 test shows that these differences are statistically significant, and that the proportion of low temperatures at Colliery A.2 was significantly higher than at Colliery A.4.

TABLE XXXIV

Percentage frequency of occurrence of various relative humidities at the coalface in certain collieries

Colliery.	No. of observations.	Mean relative humidity per cent.	Percentage of observations when relative humidity (%) was :—				
			50 to 59.	60 to 69.	70 to 79.	80 to 89.	90 and over.
A.1	53	71	4	34	56	6	—
A.3	41	83	—	2	15	71	12
A.8	52	77	4	21	31	35	9
A.7	34	84	—	6	18	41	35
A.4	66	89	—	—	3	39	58
A.2	54	94	—	—	—	15	85
B.3	63	85	—	2	17	49	32

The variability between individual observations is again illustrated in Table XXXIV, which shows the percentage frequency of occurrence of various relative humidities at the different collieries. At some of the mines the humidities were distributed over a wide range.

Along with the average thermal conditions shown in Table XXXII, the incidences of pulmonary X-ray abnormalities in the workers have been tabulated. Considering only the six anthracite mines, there appears to be a fairly good correlation between the incidence of abnormalities and the temperature at the coalface. In the hotter mines the incidence is higher than in the cooler ones. When the results for the bituminous mine, B.3, are included, they do not fall into line with those of the anthracite mines, for the average temperature at Colliery B.3, with its low incidence, was the same as the averages for some of the high or relatively high incidence anthracite mines. The data for Colliery B.3 cannot be ignored, and it is therefore clear that a relatively high temperature at the coalface is not necessarily associated with a high incidence of pulmonary disease. The data suggest rather that chilling during spake journeys may have some effect, for at each of the six anthracite mines the men ride in spakes, while at Colliery B.3 they return to the surface in the shaft and there is no spake. If, at the anthracite mines, the degree of chilling is proportional to the temperature at the coalface, there is a good correlation between such chilling and the incidence of pulmonary X-ray abnormalities. This point is examined in the next section.

It is sometimes said that the high-incidence mines tend to be dry, while the low-incidence mines are damp. Taking relative humidity as a measure of dampness—and relative humidity is correlated with subjective impressions of dampness—it does appear that within the group of anthracite mines, a high incidence of pulmonary X-ray abnormalities in the miners tends to be associated with dryness, and a low incidence with dampness. Yet we know of no reason why relative humidity of itself should exert a striking influence on the incidence of pulmonary disease. If the operative factor is the quantity of water vapour present in the air, it can be argued from Table XXXI that the lower the water content of the air, the lower is the incidence of abnormalities. In the earlier part of this report, dealing with dust concentrations, we have shown the effect of wet surfaces in reducing dust concentrations, and we suggest that the apparent

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correlation between relative humidity and the incidence of abnormalities is due not to the humidity *per se* but to the fact that in mines where the rock surfaces are visibly wet the relative humidity will tend to be higher than where such wetness is not apparent.

About twelve to fifteen years ago, in certain earlier investigations, we made many observations of the atmospheric conditions in bituminous mines in one of the English coalfields and again in Scotland, and it may be of some interest to compare the air velocities observed at the coalface in the South Wales collieries with those found earlier in the English and Scottish mines. Both longwall and pillar and stall workings were examined, but the observations in pillar and stall workings were not numerous, and the present comparison will therefore be confined to observations made on longwall faces. It should be noted that the longwall faces examined in the English and Scottish mines were mostly worked on the stall system.

Table XXXV shows the percentage frequency of occurrence of various air velocities on longwall faces in the group of six anthracite mines included in our survey, in the single bituminous mine visited in the present investigation, and in a group of seventeen English and Scottish bituminous mines. From this table it is clear that the air velocities observed in the anthracite mines were very similar to those observed earlier in the English and Scottish mines, and indeed there is no statistically significant difference between the frequency distributions shown for the two groups. At the single bituminous mine included in the present study, B.3, the velocities noted at the coalface were on the whole substantially higher than those shown for the other groups.

TABLE XXXV

Percentage frequency of occurrence of various air velocities on longwall faces in mines in South Wales and in certain English and Scottish mines

Collieries.	No. of mines visited.	No. of observations.	Percentage of observations in which air velocity (ft. per min.) was :—						
			under 25.	25 to 49.	50 to 74.	75 to 99.	100 to 149.	150 to 199.	200 and over.
S. Wales, anthracite	6	253	23.7	30.0	12.6	8.3	13.0	4.4	8.0
S. Wales, bituminous	1	63	11.1	15.9	15.9	19.0	23.8	4.8	9.5
English and Scottish, bituminous.	17	373	20.1	23.2	18.2	11.8	8.1	5.1	8.5

CONDITIONS IN THE SLANTS

1. Variations in thermal conditions between coalface and surface

At the various collieries observations were made in the slants where men ride on spakes. The temperatures in these slants are not constant. They are greatly influenced by the temperature at the surface, but the temperature in a slant at any given time does not depend only on the temperature at the surface at that time. The large mass of rock through which the slant is driven acts as a heat reservoir and tends to damp out the temperature variations. Consequently, while the temperature at the surface at the time of observation has some influence, the temperature in the slant is largely conditioned by the average temperature at the surface during a preceding period of several days.

In order that a comparison might be made of the degree of chilling experienced by the miners at the different collieries during their journey back to the surface at the end of the shift, it was necessary to ascertain the thermal

conditions in the slants for some standard temperature at the surface. In South Wales the temperature on many days during the winter months is about 40°F., and we have therefore taken that temperature as the standard surface temperature for the comparisons which follow. From observations made in the slants it has been possible to estimate with reasonable accuracy the average temperatures at the inbye ends of the spake journeys with that surface temperature. Below an account is given of the temperature changes and wind speeds encountered by the men at the various collieries on their way to the surface at the end of the shift when the temperature at the surface is 40°F.

Colliery A.1

There are two spakes at this colliery. The main spake runs in from the surface for a distance of 1,200 yards, and at the end of this journey the majority of the men change over to a subsidiary spake and ride down the main bully a further 600 yards to their district. At the inbye end of this second run the temperature is 69°F. and there is no appreciable seasonal variation.

When the surface temperature is only 40°F., therefore, these men who have been working at a temperature of 80°F. at the coalface walk to the spake while the air cools by 11°F., i.e., to 69°F., and then sit on the spakes while the air cools from 69° to 40°F. Meanwhile, they are exposed to an air velocity relative to themselves when travelling of 1,400 ft. per min. while on the secondary spake, and of 900 ft. per min. while on the main spake.

A relatively small number of men from other districts join the main spake at 550 to 1,200 yards from the surface. They experience a distinctly smaller temperature drop during their ride out.

Colliery A.3

At this colliery men ride from the surface in either of two slants, both intake airways, and in either case the length of the spake journey is roughly 1,000 yards. The thermal conditions in the two slants are very similar. During the journey towards the surface at the end of the shift the velocity relative to the spake is about 1,000 to 1,300 ft. per min., with an average of 1,200 ft. per min. At the inbye end of the spake journey the temperature is about 51°F. when the surface temperature is 40°F.

There are considerable differences between the temperatures in different districts in this colliery, and consequently the degree of chilling experienced by the men between the coalface and the surface varies according to the district in which they are employed. In one district, the coolest, the temperature at the coalface averages 67°F. On their way to the surface the colliers walk to the slant, where the temperature is 51°F., and then ride out on the spake while the temperature declines from 51° to 40°F. and the effective wind speed is 1,200 ft. per min. The greatest contrast is felt by the men working in the deepest district, where the temperature averages 77°F. and may be as high as 80°F. On leaving work they walk for some distance up a steep gradient until the spake is reached, the temperature falling meanwhile from 77° or so to 51°F. Then they ride out on the spake.

Colliery A.8

Here the men ride in from the surface on a level drift for a distance of 850 yards, but they walk out along this drift at the end of the shift. Further inbye there are subsidiary spake journeys which convey men to and from the various districts. The majority of the men are served by these inbye spakes. Both the main spake and the subsidiary ones consist of trains of tubs, so that the men are to a considerable extent shielded from the wind.

At the inbye end of the main spake journey on the level drift the temperature was estimated to be 44°F. when the surface temperature was 40°F. Between the main spake run and the subsidiary spakes the men walk for distances of 500 to

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700 yards, so that on these secondary spake routes the temperatures have less seasonal variation than in the main drift.

When returning to the surface at the end of the shift, the colliers, who have worked at temperatures averaging 69° to 73°F. at the coalface, walk some distance to the secondary spakes, where the temperature in different districts is 57° to 64°F. Then they ride in air which, by the time they dismount, cools to from 48° to 55°F. on the different routes, meeting air with a relative velocity of 500 to 1,000 ft. per min. Thereafter they walk the remaining distances to the surface, 1,350 to 1,550 yards, meeting a current with a relative speed of about 750 to 1,000 ft. per min., while the air cools from 48° or 55° to 40°F.

Colliery A.7

The main spake journey at this colliery covers a distance of only about 500 yards from the surface, and consequently the temperature at the inbye end of the journey is subject to considerable seasonal, and probably diurnal, variation. On three occasions when the surface temperature was 35·2°, 49·5° and 50·5°F. the temperature at the end of the spake run was 40·2°, 48·3° and 51·0°F.

In 1935 a subsidiary spake was arranged in one seam at this colliery, but in considering the incidence of pulmonary disease which has taken some time to develop this recent innovation can be ignored.

In different seams the temperatures at the coalface averaged from 67° to 72°F. At the end of the shift the men walk to the spake in air which, when the surface temperature is 40°F., eventually cools to 43°F. by the time they arrive at the spake, and then during their short ride on the spake they meet an air current of about 2,000 ft. per min. relative velocity, while the temperature declines by 3° to 40°F.

Colliery A.4

The spake journey from the surface down the main slant is a distance of about 850 yards. At the inbye end of the journey the temperature averages about 48° when the surface temperature is 40°F. Returning to the surface at the end of the shift, the men leave the coalface, where the temperature is 62° to 69°F. in different seams, and make their way to the spake, by which time they have reached air at a temperature of 48°F. While they ride on the spake the temperature falls to 40°F. and the effective wind speed varies from 1,000 to 1,500 per min.,

Colliery A.2

Until comparatively recently there have been no subsidiary spakes at this colliery, and the inbye spakes now in use can be disregarded for the purpose of this discussion. The men working in two of the three districts ride to and from the surface in the main slant, the men from one district over a distance of 350 yards, and those from the other a distance of 800 yards. The men from the remaining district walk their slant.

When the surface temperature is 40°F., the men on their journey to the surface from one district leave the coalface, at a temperature of 67°, and walk to the spake, where the temperature has fallen to 58°F. Then, as they are hauled to the surface for 800 yards, they meet an air current of 600 ft. per min. while the temperature falls to 40°F. The men from another district walk from the coalface to the slant, in air which cools from 60° to 50°F., and then, while sitting on the spake, they are exposed to a current of 600 ft. per min., which cools by a further 10° to 40°F. The men from the remaining district, before the inbye spake was introduced, walked out from the coalface, with its temperature of about 60°, to the surface, meeting an air current of 400 ft. per min. during their walk of 250 yards up a slant.

2. Chilling on the spakes

Table XXXVI summarises the temperature changes experienced by the men when riding on the spakes. In order to express in a single index these changes

TABLE XXXVI

Temperature changes experienced by the men when riding up the slants at various collieries.

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of expected incidence.	Length of spake journey (yards).	Environmental conditions :—						Drop in effective temperature during spake ride, ° F.	Effective temperature at the coalface, ° F.	
			at bottom of slant before start of spake journey.			finish of spake ride at top of slant.					
			D.B. temperature, ° F.	Air velocity, f.p.m.	Effective temperature, ° F.	D.B. temperature, ° F.	Air* velocity, f.p.m.	Effective temperature, ° F.			
A.1	233	1,800	69	680	56.3	40	1,150	15.4	40.9	73.0	
A.3	172	1,000	51	750	34.9	40	1,200	15.4	19.5	67.1	
A.8	146			(see Table XXXVII)							
A.7	95	500	43	900	21.0	40	2,000	10.4	10.6	67.0	
A.4	55	850	48	190	41.0	40	1,250	15.4	25.6	64.6	
A 2 { 11's	12	800	58	400	46.8	40	600	21.9	24.9	26.0	60.8
5's		350	50	30	49.0	40	600	21.9	27.1		

*Relative to moving spake.

TABLE XXXVII

Temperature changes during return to surface at Colliery A.8

District.	Length of spake journey (yards).	Men leave district at conditions of			Ride on inbye spake to conditions of			Walk to surface to conditions of			Drop in effective temperature during spake ride, ° F.
		D.B. temperature, ° F.	Velocity, f.p.m.	Effective temperature, ° F.	D.B. temperature, ° F.	Velocity, f.p.m.	Effective temperature, ° F.	D.B. temperature, ° F.	Velocity, f.p.m.	Effective temperature, ° F.	
A	800	64.3	38	61.0	47.5	1,000	25.2	40	1,000	16.5	35.8
B	1,050	58.7	25	57.0	47.5	1,000	25.2	40	1,000	16.5	31.8
C	1,300	56.8	200	49.8	54.8	500	42.1	40	1,000	16.5	7.7

in thermal conditions, we have calculated the effective temperatures at the beginning and end of the spake journey, so that the change at a particular colliery can be expressed in terms of the drop in effective temperature. The wet bulb temperature used in computing the effective temperature at the bottom of the slant is based on actual observations, and for the effective temperature just before the surface is reached, we have assumed the wet bulb temperature corresponding to a relative humidity of 80 per cent. at 40°F. The air velocity quoted for the beginning of the spake journey is the actual rate of movement of the air in the slant. That used for the end of the spake journey is the velocity relative to the moving spake, and it represents the conditions just before the mouth of the slant is reached. Table XXXVI includes data for each of the anthracite mines except Colliery A.8, i.e., each of the mines where the men are ridden out to the surface. The changes experienced by the men at Colliery A.8 in riding outbye on the subsidiary spakes are summarised in Table XXXVII.

It might at first sight appear that, since the men at Colliery A.8 walk out the last 1,350 to 1,550 yards to the surface, they will not be exposed to any substantial chilling, but the drop in effective temperature noted in Table XXXVII is, for two of the three districts, larger than any shown in Table XXXVI except that for Colliery A.1. At Colliery A.8 the men are conveyed in tubs instead of on the usual trolleys; they are thus sheltered from the wind to some extent, but, nevertheless, they must be severely chilled during their ride.

The greatest effective temperature drop occurs at Colliery A.1, where the incidence of pulmonary X-ray abnormalities is highest, but among the other collieries mentioned in Table XXXVI there is no clear correlation between temperature drop and incidence of lung disease.

The fall in effective temperature does not, however, truly represent the degree of chilling experienced. If the temperature change is sudden, and the men are physically inactive for only a very short time, they may not be much chilled before they are able to maintain their bodily warmth by muscular exertion, but if the chilling takes place over a longer period the same fall in temperature may induce serious chilling. Hence, in considering the degree of chilling, attention must be paid to the length of the spake journey as well as to the temperature change. Another factor which must also be borne in mind is the temperature at which the men have worked during their shift, for a given change of temperature and period of exposure will be more or less serious according as the men have been working in hot or relatively cool places.

In comparison with some other coalfields, the temperatures at the coalface in the mines visited in this investigation were not very high, and we rarely if ever saw men stripped to the waist; they wore at least a singlet. In some of the mines the temperatures were high enough to cause considerable sweating in men doing hard physical work, with the result that the clothing worn by the miners became very damp. It is not the practice in this coalfield to change into dry clothes on leaving the coalface, and consequently exposure to a strong air current of low temperature during the ride outbye results in far worse chilling than would occur if the men donned dry garments before returning to the surface.

When regard is paid to all these factors, there appears to be some tendency for a high incidence of pulmonary X-ray abnormalities to be associated with a substantial degree of chilling on the spakes, but the association is not a close one, and, while chilling may have had some effect on the incidence of the disease, we conclude that it cannot have been a major factor in its causation.

3. Discussion

The conclusions reached by us are opposed to the views expressed by T. D. Jones and by Haldane, Haynes, Shaw and Graham, and some comment

is desirable. The claim that the primary cause of the pulmonary disease amongst anthracite miners is bronchitis contracted by the miners through repeated chilling when riding on spakes appears to be based on tables given by Jones (1935 and 1936), in which he contrasts the numbers of certified silicosis cases at collieries with spakes and at collieries without spakes. These tables certainly show striking differences. Thus, Jones (1936) gives the numbers of cases certified per 100 men employed up to the end of 1935 as 3·24 in the collieries with spakes and only 0·41 in those without spakes.

In the discussion on his 1936 paper, Jones defied any attempt to draw from these facts any conclusion other than the one which he had reached, namely, that the harm attributed to dust in anthracite mines is really due to bronchitis resulting from chilling on the spakes, with secondary accumulation of coal dust following on the bronchitis. His figures certainly appear to indicate some association between a high incidence of silicosis and the provision of spakes, but they give no proof of a causal relationship. Jones has insistently attributed the trouble to spakes, and has scouted the idea that dust is the causative agent, but he has apparently made no attempt to produce proof which would exonerate dust from blame. An obvious fault in the tables referred to (Tables XIX and XV of his 1936 paper), and one very damaging to his thesis, is the absence of any evidence concerning the dust concentrations in the two groups of collieries. As the tables stand, they are open to the interpretation that the presence or absence of spakes may be in some way linked with factors concerned with the dustiness of the mines, and that the association between silicosis and spake-riding may thus be an indirect one. For instance, in the absence of any statement to the contrary, it is conceivable that the collieries without spakes were shallower and wetter than those at which spakes were provided, and that the dust concentrations were in consequence decidedly lower in the collieries without spakes than in the others.

While we are entirely opposed to the view that exposure on the spakes is mainly, or even largely, responsible for the abnormalities found among the colliers, we agree that the chilling is often serious and highly undesirable. We are entirely in accord with the recommendations made by Jones (1936) : (i) that wherever possible spakes should be run in the return airways ; (ii) that the best form of protection is probably individual rather than collective, and that protective garments, possibly incorporating some kind of cowl, are desirable ; and (iii) that if hoods or windscreens were provided on the spakes they would give valuable protection.

Concerning the last suggestion, we understand that in some cases where hoods or windscreens have been installed, the miners have disapproved of them, on the ground that they are liable to hinder ready escape from the spake in the event of derailment or other emergency. It may be added that windscreens are already provided on the spakes at some of the collieries visited by us.

We further suggest that the miners could do much to avoid chilling on the spakes if they could put on dry undergarments on leaving the coalface at the end of the shift.

SUMMARY

1. The thermal conditions at the coalface and in the slants at six anthracite collieries, and at the coalface of one bituminous mine, have been investigated.
2. It is concluded that atmospheric humidity of itself has no influence on incidence of pulmonary disease. Any apparent influence of humidity is probably due to the effect of wet strata surfaces in diminishing dust concentrations.
3. Within the group of anthracite mines the higher incidences of pulmonary X-ray abnormalities were found at the collieries with the higher temperatures at

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the coalface, but when the single bituminous mine included in the survey was taken into account, it appeared that a relatively high temperature at the coalface was not necessarily associated with a high incidence of abnormalities.

4. There appears to be some association between the incidence of pulmonary X-ray abnormalities and the degree of chilling experienced when riding in spakes, but the association is not very close, and it is concluded that while chilling may have had some effect in the causation of the disease, it cannot have played a major part.

5. It is suggested that, wherever practicable, the spakes should be run in return airways; that protective clothing is desirable; and that consideration be given to the general provision of hoods or screens on the spakes. It is also suggested that dry underclothing should be put on by the miners at the end of the shift.

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CHRONIC PULMONARY DISEASE IN SOUTH WALES COAL-MINERS II.—ENVIRONMENTAL STUDIES

C.—MASS CONCENTRATIONS OF AIR-BORNE DUST AND MINERAL MATTER IN CERTAIN COALMINES

BY

H. V. A. BRISCOE, A.R.C.S., D.Sc., D.I.C., F.I.C.

P. F. HOLT, Ph.D., D.I.C., F.I.C.

N. SPOOR, A.R.C.S., Ph.D., D.I.C., A.I.C.

JANET W. MATTHEWS, Ph.D., D.I.C., F.I.C.

AND

PHYLLIS M. SANDERSON, Ph.D., D.I.C.

(Department of Inorganic and Physical Chemistry, Imperial College of Science and Technology, London)

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INTRODUCTION

When the recent inquiry into the incidence of chronic pulmonary disease in the South Wales coalfield was projected, it was generally agreed among those responsible for directing the investigation that it was necessary to secure, in parallel with the medical survey, the fullest possible knowledge of the present environmental conditions of the miners at work, so that some estimate, at least, might be made of the conditions to which they had been exposed during the long period over which any pneumokoniosis found among them must have been contracted.

Very important examples of these conditions were, evidently, the mass concentration and the chemical nature of the dust particles inhaled at the coalface, and these factors were accordingly studied by various methods which the authors had developed for such purposes. In earlier observations on the chemical reactivity of potentially dangerous dust (Matthews & Briscoe, 1934-5, 1937; Briscoe, 1939), stress had been laid on the necessity for obtaining samples of such dust exactly *as the worker breathes it*; methods had accordingly been devised which were capable of collecting substantially the whole of the solid matter in the volume of dusty air taken as a sample, and of yielding it, after suitable treatment, concentrated in a convenient vessel for weighing or analysis, without loss or contamination, without contact with water or any other material which might cause chemical changes in the solid, and without heating much above 50°-70°C.

A major difficulty in sampling industrial dusts is inherent in their very low concentration. Many dangerous atmospheres, such as those of flint-crushing

plants, pottery workshops, metal mines and asbestos factories, frequently contain only about 1 or 2 milligrams of dust per cubic metre, and even very dense dust clouds, like that in which a collier works at the coalface, often contain only about 100-200 mg. of solid per cubic metre, while in most parts even of a fairly dusty coalmine the dust concentration is between 5 and 20 mg. per cubic metre.

It is therefore necessary in sampling to handle relatively large volumes of the dusty air, some 5-10 litres being required for even the smallest samples, of 0.2-2 mg., used to determine mass concentration; the collection of large samples of, say 10-200 g. weight may, in extreme cases, mean dealing with as much as 100,000 cubic metres or more of air.

THE SAMPLING OF DUSTY ATMOSPHERES

In the earliest stages of the investigation apparatus designed for the collection of the larger types of samples, the "labyrinth" and the "soluble solid filter", were both used in exploratory work upon the nature of the dust solids present at the coalface and in other parts of the workings; the results so obtained, though they performed an essential function in building up the sampling procedure finally used for the main study of dust and ash concentrations, bear no direct relation to the results of the medical investigation and need not be discussed here. As a result of this preliminary survey, however, it was agreed by all concerned that the purpose of the whole investigation could best be served by restricting this section of it to an extensive study of the mass concentrations of air-borne dust, and of mineral matter other than coal (ash) in that dust, in the atmospheres at and immediately adjacent to the face in which the collier normally works. For this purpose the "volatile solid filter", with naphthalene as the filter bed, was employed. At the same time, 25 large samples for more detailed study were collected by means of a fabric filter, in the manner described in another report in this volume (p. 96).

The Naphthalene Filter

The design of the "naphthalene filter" as used in this work is shown in Fig. 10.

A perforated brass disc A, which serves as the support for the filter bed, is carried by a short length of tube B, which is split and sprung as shown, so that it slides snugly into the outer casing C; the tube B is positioned by the shoulder turned in the casing, so that the disc lies some 7-8 mm. from the outer end. The space above the disc is filled loosely with powdered naphthalene, which is then compressed by a smooth-ended brass plunger. With a filter 10 mm. in diameter a suitably compressed pad is obtained with a load of about 15 kilograms on the plunger, the latter being designed, as shown at D, so that the pressure applied through a calibrated spring can be conveniently observed and controlled. When the filter has thus been prepared in the laboratory it is rolled up in a sheet of cellophane, and with this airtight protection it will keep, ready for use, for weeks, even in very wet and dirty surroundings.

In an extensive campaign of sampling, such as was involved in the present work, it is necessary to have a large stock of filters (some 200 in all were used).

The naphthalene must be very pure and substantially free from any non-volatile residue: it should also be in a suitable mechanical form. The purest naphthalene is therefore redistilled slowly through a scrubber column, to secure a distillate free from all trace of dust or other non-volatile impurity, and the solidified distillate is crushed and sifted through a 20-mesh gauze to yield a moderately fine powder.

For use in the underground workings of coalmines, the naphthalene filter has the great advantage that its manipulation is very simple and can be performed

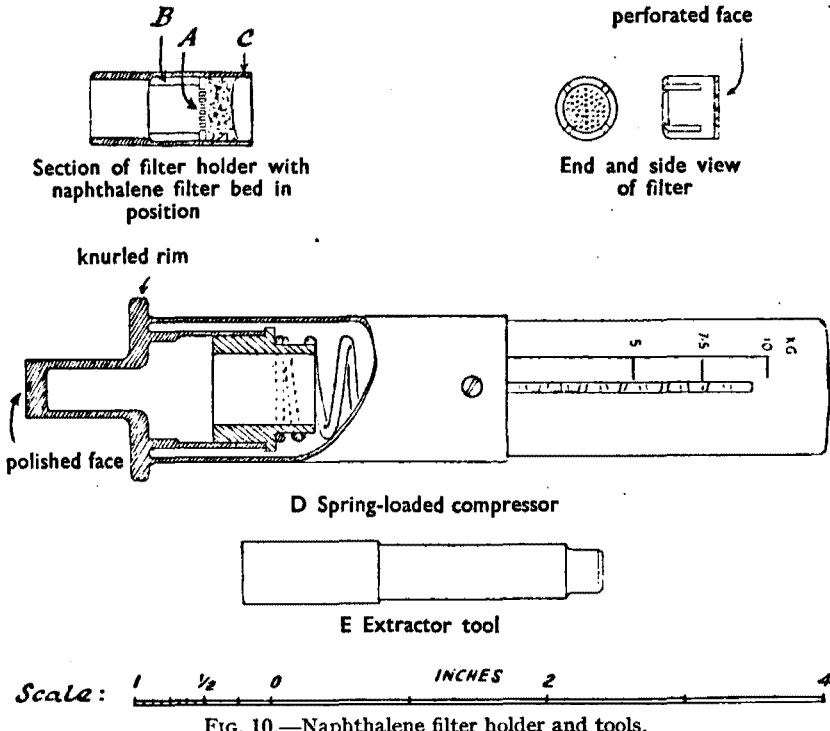


FIG. 10.—Naphthalene filter holder and tools.

under extremely wet and dirty conditions, with very little risk of error through contamination or other accident, as may be seen from the following description of the procedure.

Before use of a filter, the cellophane is removed, generally by cutting it round the centre and pulling off the two ends; the brass filter tube is then fitted firmly into a rubber connector attached, either directly or by a long rubber tube, to the pump or aspirator used to draw the sample. For measurements of mass concentration, i.e., weight of dust per unit volume of air, it is necessary that the volume of air drawn through the filter shall be accurately known. To take such samples from about 5 litres of air in a period of 5 or 6 minutes, a calibrated hand suction pump, drawing about 170 ml. per stroke, serves well; to take average samples over a longer period, a similar volume of air is drawn through the filter over a period of 2 to 3 hours, by means of a water aspirator. The sample having been taken, the filter is immediately wrapped again in clean cellophane and returned to its carrying case, which may conveniently be a sort of cartridge holder slung across the shoulder of the operator.

DETERMINATION OF MASS CONCENTRATION OF DUST AND ITS ASH

When the used filter is received in the laboratory, the filter-pad and support are pushed out of the casing by means of a brass plunger (shown as E, Fig. 10): this is made to fit into the base of the filter support A, so that the pad can be detached and placed, dusty side down, in a tiny shallow platinum dish which has previously been weighed on the micro-balance. The dish is then placed, with others, suitably covered and protected from draughts, on a copper block electrically heated to 70°C., and there left overnight. By morning, the naphthalene has all sublimed away, and the pure uncontaminated dust is left as a residue, the weight of which can be accurately ascertained by reweighing the dish.

TABLE XXXVIII

A typical selection of naphthalene filter data from Colliery A.3

No.	Date.	District.	Place.	Operation.	Type of samples.	Pump, strokes.	Volume of air : litres.	Weight of dust : mg.	Weight of ash : mg.	Mass concentration of dust : mg/m ³	Ash : %	Mass concentration of ash : mg/m ³
93	24.4.40	70's Middle Deep ..	Stall ..	2 men picking and shovelling coal.	C	20	3.40	5.169	0.358	1522	6.9	105
99	24.4.40	Middle Deep ..	Stall ..	1 man picking coal	C	35	5.95	0.899	0.157	151	18.6	26
107	24.4.40	Middle Deep ..	Stall ..	2 men filling tubs	C	15	2.55	2.392	0.219	938	9.2	86
108	24.4.40	Middle Deep ..	Stall ..	2 men picking coal	C	25	4.25	1.666	0.234	392	14.0	55
109	24.4.40	Middle Deep ..	Stall ..	2 men filling tubs	C	25	4.25	1.278	0.130	301	10.2	31
74	24.4.40	Middle Deep ..	Place ..	2 men shovelling coal ..	C	20	3.40	1.809	0.162	532	9.0	48
75	24.4.40	Middle Deep ..	Stall ..	2 men box-filling tub ..	C	25	4.25	1.343	0.130	316	9.7	31
76	24.4.40	Middle Deep ..	Stall ..	1 man picking and shovelling	C	10	1.70	1.388	0.142	816	10.2	83
134	26.4.40	Middle Deep ..	Stall ..	2 men picking and filling coal	C	30	5.10	2.553	0.204	500	8.0	40
136	26.4.40	Middle Deep ..	Stall ..	2 men filling tub	C	35	5.95	1.411	0.132	237	9.4	22
137	26.4.40	Middle Deep ..	Level ..	2 men filling tub	C	15	2.55	4.066	0.328	1594	8.1	129
144	26.4.40	Middle Deep ..	Stall ..	1 man filling	C	50	8.50	0.832	0.104	98	12.5	12
61	23.4.40	Middle Deep ..	Place ..	2 men filling rubbish ..	M	60	10.20	0.631	0.154	61	24.4	15
68	23.4.40	Middle Deep ..	Place ..	2 men filling rubbish ..	M	60	10.20	1.019	0.413	100	40.5	40
86	24.4.40	Middle Deep ..	Stall ..	2 men filling rubbish ..	M	50	8.50	0.889	0.365	105	41.1	43
87	24.4.40	Middle Deep ..	Stall ..	2 men filling rubbish ..	M	45	7.65	2.955	1.235	386	41.8	161
143	26.4.40	Middle Deep ..	Stall ..	2 men timbering & setting cog.	I	120	20.40	0.719	0.127	35	17.7	6

Since the dish is of platinum, it is possible, although the whole sample may weigh only a milligram or less, to go further and make some chemical examination of the residue. In the present work the coal dust samples were treated, after the first weighing, by ignition at about 500° C. to burn away the carbon, the dish then being reweighed to show the percentage of ash in the coal dust. It may be remarked that the ashing of such small quantities of coal is a very rapid process, taking only 1 to 2 minutes. In some cases, the ash may subsequently be treated with sulphuric acid and hydrofluoric acid to volatilise the silica and then again ignited and reweighed, so as to show approximately the percentage of total silica present. The data obtained from a typical series of samples are recorded in Table XXXVIII. It is upon some 800 results of this kind that this report is based, the calculated figures in the last three columns having been examined statistically in the manner described below.

Tests made under various conditions (Briscoe and Matthews, 1937; Briscoe, Matthews, Holt and Sanderson, 1936-7) have shown that a naphthalene filter, properly made and used, will collect 98 to 99 per cent. of the total solid matter present in the air passing through it, and that no loss of dust occurs during the subsequent sublimation of the filter bed. The precision of the mass-concentration data, though not of the ash percentages, depends also upon the precision of the volume measurement; this, though less accurate than the weighings and analyses, has an error which is only of the order of ± 2 per cent. There is thus, in our opinion, no reason to doubt that the individual determinations are sufficiently accurate for their purpose.

STATISTICAL EXAMINATION OF THE RESULTS

Regarding the whole body of results, however, it is clear that the *average* values for coal and ash concentration in the dust, which must necessarily be used for consideration in relation to the medical findings, are attended by the relatively large uncertainties inherent in any averages of data varying over wide ranges. We are, therefore, greatly indebted to Dr. T. Bedford and Dr. C. G. Warner for having kindly made a statistical examination which, as it affords the best mode of presenting our results, is here given in detail.

In all, about 800 naphthalene filter samples were taken and examined in the laboratory, from the 12 collieries A.1, A.2, A.3, A.5, A.6, A.8, B.1, B.2, B.3, S.3, S.4 and S.5. Generally, three or four days were spent in taking the samples at each colliery, and about as many weeks in carrying out the precise quantitative work on these in the laboratory. The number of samples taken at each mine varied from 30 to 115, but was usually about 50 to 60, this being deemed sufficient to give a fair sample of the whole set of varying concentrations to which the collier is subject throughout the working shift.

At each colliery one to four separate districts were visited, and in each district some 30 samples were taken over a working shift. The samples were taken, each over a period of 5-35 minutes, when men were working at some definite operation at the coalface; they were drawn at breast height, near to and on the uptake side of the men at work and, in general, within 2-6 ft. of the coalface. The volume of air sampled was varied with the concentration (by visual judgment of the staining of the filter face) so as to secure a weight of dust of the order of one or two milligrams, convenient for subsequent analysis. The volume of air per sample thus ranged from about 0.5 litre to about 20 litres.

The samples are divisible into three groups (C), (M) and (I); the (C) samples were taken when the coal was being won or handled; the (M) samples during the work of ripping or the handling of rippings ("mucking") and the (I) samples when various tasks were being performed intermittently. The (I) samples were small in number and related to such a variety of operations that they could not well be submitted to separate statistical treatment. It is a matter of interest,

however, to determine how far the dust created by ripping operations differs from that produced by coalgetting and handling, and, though the (M) samples are not numerous, it has been possible to examine the differences between the (C) and (M) samples by applying Fisher's method for the statistical treatment of small numbers of observations.

It should be noted that the collier sometimes disturbs the clod overlying the coalseam and may thus breathe the dust produced from both clod and coal. This is especially the case in Colliery A.6, where the samples were taken at conveyor faces in which the top clod was unusually thick. Another difficulty in analysing the data arises from the fact that the dust breathed or sampled in any stall consists only in part of dust actually produced in that stall; a percentage of the air-borne dust originates further along the face and is carried along in the ventilation current. Thus it is possible for an appreciable proportion of the dust collected as a (C) sample to have resulted from (M) operations further down the face, and this is especially true for the finer fractions. However, at most collieries this grouping of the samples has been a natural one, and it has certainly proved useful. For the comparison of the dust concentrations at the several collieries, and for the correlation of the dust and ash concentrations with the X-ray findings, the average of *all* the observations made at each colliery has been taken, with the one exception (A.1) noted later.

The Relative Influence of Coalhandling and Ripping on Dust Concentration

In comparing the dust concentrations and ash percentages observed during these two groups of operations, (C) and (M) respectively, the significance of the differences between means has been tested by the application of the "t" test, from which the probability that an observed difference may be due to chance can be calculated. The mean values at eleven collieries are shown in Table XXXIX. At the twelfth colliery, A.6, no ripping samples were taken. The values given in the columns headed *P* are the calculated probability that the difference between the means is due to chance. A probability of 0.20 indicates that the observed difference between the means might be expected to occur by chance 20 times in 100 observations, whereas a *P* value of 0.01 means that the chances are 99 to one against a merely accidental occurrence of the observed difference. It is considered that a *P* value not exceeding 0.05 (*viz.*, a 5 per cent. chance that a difference is accidental) may properly be taken to indicate that the difference is real.

On this basis, considering first the mass concentrations of total dust (coal plus other minerals), it will be observed that the mean values for the two operations differ significantly at five collieries. At Colliery B.3 the mean concentration was higher during ripping than when coal was being got and handled, but at the other four collieries where significant differences were observed the average dust concentration was higher during the handling of coal. Considering now the ash content of the dust, it is seen that at all of the eleven collieries the percentage of ash in the dust was significantly and substantially higher during ripping than during coalgetting and handling. On the other hand, while at two collieries, B.3 and S.4, the mass concentration of ash in the air was significantly higher during ripping than during coalhandling, it is noticeable that at the remaining nine collieries the differences in ash concentration were not significant.

The one clear conclusion appears to be that, as might be expected, when ripping is in progress the percentage of ash in the dust is markedly higher than when the men are working in coal. Less sure inferences are (i) that in most cases the getting and handling of coal produces higher mass concentrations of dust than ripping and "mucking", and (ii) that, on the whole, there is a tendency for the mass concentration of ash to be higher during ripping than during coalhandling, though this relation does not hold at all the collieries.

TABLE XXXIX

Comparison of dust concentrations during the work of coalhandling and of ripping

Colliery.	Number of samples during operation of		Mass concentration : mg. per cub. metre.			Ash percentage.			Ash concentration : mg. per cub. metre.		
	Coal-handling.	Ripping.	Mean values for		P*.	Mean values for		P*.	Mean values for		P*.
			Coal-handling.	Ripping.		Coal-handling.	Ripping.		Coal-handling.	Ripping.	
A.1†	10	9	190	105	0.20-0.30	16.0	25.7	Less than 0.01	28.5	25.2	0.70-0.80
A.2	69	14	517	213	0.02	10.5	24.4	Less than 0.01	47.8	35.7	0.30-0.40
A.3	59	5	599	231	0.20-0.30	11.3	34.7	Less than 0.01	64.7	78.0	0.60-0.70
A.5	48	16	441	184	Less than 0.01	10.9	18.6	Less than 0.01	45.5	31.8	0.10-0.20
A.8	48	4	675	161	0.02-0.05	10.3	26.8	Less than 0.01	67.1	37.8	0.20-0.30
S.3	69	10	316	159	Less than 0.01	12.8	28.5	Less than 0.01	38.6	51.2	0.20-0.30
S.4	65	10	253	160	0.20-0.30	9.3	26.1	Less than 0.01	21.9	38.8	0.02-0.05
S.5	54	5	288	208	0.30-0.40	10.6	23.2	Less than 0.01	28.0	41.8	0.10-0.20
B.1	49	8	301	424	0.30-0.40	15.5	30.4	Less than 0.01	46.4	78.4	0.10-0.20
B.2	37	9	329	110	0.05-0.10	17.1	39.1	Less than 0.01	52.3	61.2	0.70-0.20
B.3	66	26	84	151	Less than 0.01	21.8	35.0	Less than 0.01	16.1	55.4	Less than 0.01

* P is the probability that the difference between the means is due to chance.

† Data for Douglas district only.

RELATIONSHIP OF MASS-CONCENTRATION DATA TO INCIDENCE OF PULMONARY ABNORMALITIES

The Bearing of Present Observations on Former Conditions

As has already been remarked, a major difficulty in any attempt to relate the dust determinations to the medical findings in this investigation lies in the fact that, whereas the dust measurements have all been made within the last year or two, the pulmonary abnormalities found by the medical investigators have been contracted over a period of many years; thus, we neither have nor can hope to get any direct and precise knowledge of the nature and concentration of the dust solids which actually produced the lung changes observed.

There could, obviously, be no certainty that the dust hazard had remained constant over the period of 10 to 20 years involved, and such slight evidence as can be secured on the point suggests that in many cases substantial changes, at least in dust concentration, have occurred in this period, sometimes in a downward direction. The following paragraphs outline the information gleaned on this point.

(i) *Colliery A.1*—In the preliminary stages of the sampling campaign notable differences were found between the concentrations in the "Douglas" district and in the Main Bully. The management at Colliery A.1 had volunteered to open up the new district called "Douglas," in the hope that it might thus be possible to reproduce the conditions of low ventilation and enhanced dustiness characteristic of the workings of twenty years back. When, however, the conditions in the newly created Douglas district were investigated, it was a disappointment from the point of view of the inquiry (though an interesting index of the general improvement which recent years have seen in colliery conditions) to find that it was impracticable to reduce the ventilation to the earlier levels. Because of the relatively good ventilation and the small number of working places in the Douglas district, the dust concentrations there were certainly much lower than those common in the mine some years ago. On the other hand, although, owing to its distance inbye, the Main Bully district may possibly be a little dustier than the general average of the mine five or ten years ago, it probably does not greatly exaggerate that dustiness. Thus, in so far as this colliery is included in the general comparison of dust concentrations with medical findings, it is probably advisable to use the results obtained in the Main Bully and to ignore those for the Douglas district. This has been done in compiling Table XL.

TABLE XL

Average dust concentrations and ash percentages from naphthalene filter samples in relation to pulmonary X-ray abnormalities

Colliery.	Observed incidence of X-ray abnormalities ("consolidations") as percentage of "expected" incidence.	Number of dust samples.	Concentration of total dust : mg. per cub. metre.		Ash percentage.		Ash concentration : mg. per cub. metre.	
			Mean.	S.E. of mean.	Mean.	S.E. of mean.	Mean.	S.E. of mean.
A.1*	233	8	770	136.5	13.1	0.26	99.8	17.89
A.6	176	50	462	32.6	19.2	0.89	86.2	6.39
A.3	172	71	535	72.5	13.3	0.95	61.4	8.27
A.8	146	58	584	64.5	12.2	0.93	60.7	6.28
S.3	110	82	296	18.8	14.7	0.99	40.2	3.45
B.1	39	61	308	41.1	18.0	1.37	50.2	7.02
S.5	35	62	273	23.0	11.6	0.90	28.5	2.54
A.2	12	85	457	49.4	12.8	0.96	44.9	5.12
S.4	12	78	243	26.3	11.9	1.07	25.7	3.03
B.3	4	115	94	9.5	26.5	0.96	25.6	3.47
B.2	0	46	287	45.8	21.4	2.26	54.0	9.23
A.5	0	64	377	39.7	12.8	0.76	42.0	4.10

*Data for Main Bully only (see text).

(ii) *Colliery A.3.*—In 1936, alterations were made in the ventilation arrangements, which had important effects on the circulation of air throughout the mine. Not only was the ventilation volume materially increased, but also the alignment of the longwall faces has latterly been so improved as to ensure a better utilisation of the available air in scavenging the working places. Moreover, in recent years longwall working has become the rule, whereas previously there had been a good deal of narrow-stall or double-stall working, and in places of this type the degree of ventilation obtainable with a given main air-flow is substantially less than on a longwall face. It seems not improbable, therefore, that the dust concentrations measured at this colliery during the present investigation considerably underestimate the hazard to which the colliers now suffering from pulmonary disability were exposed during the relevant period of their working lives. In the comparison given later in this report the data for A.3 have been used without adjustment, so that, in considering their significance, it is necessary to keep in view the opinion outlined above. There is, for example, little doubt that the point shown for A.3 in Fig. 11 should lie considerably to the right of its present position, a change which would materially improve the correlation of ash concentration with incidence in the higher ranges.

(iii) *Collieries A.2, A.8 and B.3.*—Discussions with the managements strongly suggest that in these three collieries the present conditions of dustiness are probably closely similar to those which have prevailed for many years, and

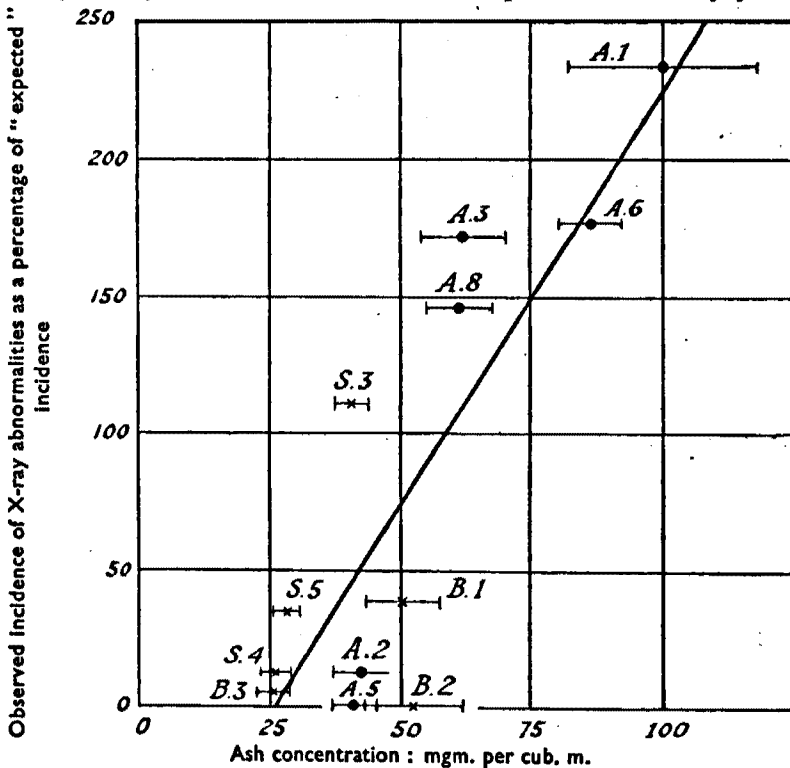


FIG. 11.—Relation between incidence of X-ray abnormalities and ash concentration in certain South Wales collieries. The points (●) in anthracite pits, X in steam coal and bituminous coal pits) show the average ash concentrations observed. The horizontal line drawn through each point measures the standard error of that mean. The heavy oblique line is drawn to the regression equation calculated from the coefficient of correlation between incidence of X-ray abnormalities and ash concentration for the group of 12 collieries.

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it may be remarked that the points representing the results obtained at these collieries lie not far from the oblique line in Fig. 11.

(iv) *Other Collieries.*—In the other collieries included in this survey it has not been possible to form any clear opinion as to how far the dust concentrations recently measured may be taken as representative of earlier conditions.

Correlation of the Available Data

In Table XL the collieries are shown in order of decreasing incidence of pulmonary X-ray abnormalities. The figure used as a measure of that incidence is the number of observed cases of "consolidation" expressed as a percentage of the "expected" number of such consolidations. The manner in which this "expected" number is calculated is fully described in the report of the medical investigators; it will suffice here to say that it is based on the medical findings in the eight anthracite collieries included in the investigation, and represents the number of "consolidations" which would have been found if the number of men examined at the particular colliery (whether anthracite or non-anthracite) had had the incidences of "consolidation" (for men of under 10, 10 to 20, and over 20 years employment as a collier) of the whole collier population of the eight anthracite mines. In the body of the table are shown, in relation to these incidences, the average mass-concentration of dust, the average mass-concentration of ash, and the average percentage of ash, together with their standard errors.

Inspection of the table suggests that there is a tendency for the higher incidences of pulmonary X-ray abnormalities to be associated with higher average dust concentrations, and to test this point the coefficients of correlation between the incidence figures and the average dust values have been calculated. The first series of correlation coefficients were calculated for all the twelve collieries mentioned in the table, regardless of the nature of the coal mined. Further coefficients were computed for the eleven collieries which remain when Colliery A.1, where the pertinent dust observations are few, is excluded. As it is of some importance to decide how far any conclusions on the relation between pulmonary abnormalities and dust concentrations apply within the anthracite area, further correlations have been calculated: (a) for the six anthracite collieries included in Table XL, and (b) for the five collieries excluding Colliery A.1. The correlation coefficients are shown in Table XLI. Since the

TABLE XLI

Correlation of incidence of X-ray abnormalities with average dust concentrations and ash percentages

<i>Group of observations.</i>	<i>Number of observations.</i>	<i>X-ray findings correlated with</i>	<i>Coefficient of correlation (r)</i>	<i>P</i>
All collieries ..	12	Total dust concentration	+0.80	Less than 0.01
		Ash concentration ..	+0.83	Less than 0.01
		Ash percentage	-0.23	More than 0.10
All collieries except A.1	11	Total dust concentration	+0.68	0.02-0.03
		Ash concentration ..	+0.73	0.01-0.02
		Ash percentage	-0.20	More than 0.10
All anthracite collieries	6	Total dust concentration	+0.78	0.05-0.10
		Ash concentration ..	+0.90	0.01-0.02
		Ash percentage	+0.50	More than 0.10
Anthracite collieries except A.1 ..	5	Total dust concentration	+0.71	More than 0.10
		Ash concentration ..	+0.87	0.05-0.10
		Ash percentage	+0.95	0.01-0.02

numbers of observations on which these coefficients are based are very small, the formula which is generally used for calculating the standard error of a correlation coefficient cannot be applied. Use has therefore been made of the "t" test to ascertain the probability that coefficients such as were observed could arise by random sampling if there were no real correlation between dust concentrations or ash percentages and the incidence of X-ray abnormalities. This probability figure is shown in Table XLI under the heading "P".

Considering first the total dust concentrations, it will be seen from the table that when all the collieries are taken into account, whether Colliery A.1 be included or excluded, there is a significant correlation between the incidence of pulmonary X-ray abnormalities and the magnitude of dust concentrations. When, on the other hand, the comparison is limited to the anthracite collieries only, whether Colliery A.1 is included or not, the correlation is not significant.

Turning to the correlations with ash concentrations, it is seen that in each of the four series of calculations the correlation of X-ray abnormalities with ash concentrations is higher than that with the concentration of the total dust. In no case is the difference between the two coefficients statistically significant, but it may be thought that the regularly higher coefficients for ash concentration suggest that the apparent relation may be real. Again, whereas in the group of six anthracite collieries the total dust gives no significant correlation with the medical findings, the ash concentration gives a highly significant correlation, and indeed even in the group of five anthracite collieries excluding A.1 the correlation with ash concentration is such as would be expected to arise by chance only about 5 times in 100 trials. This relationship is expressed graphically in Fig. 11, where the horizontal lines measure the standard errors of the points through which they pass. In this figure the heavy oblique line is drawn to the regression equation calculated from the coefficient of correlation between incidence of pulmonary X-ray abnormalities and ash concentration for the group of twelve collieries.

Of the correlations between X-ray abnormalities and ash percentages, the only significant one is for the group of five anthracite collieries excluding Colliery A.1. No stress can be laid on this coefficient, however, for inspection of Table XL shows that at four out of the five collieries the ash percentages were almost identical, and the high correlation noted is due to the occurrence of a higher percentage at the high incidence mine, A.6. It may well be concluded that the incidence of pulmonary abnormalities is not related to the ash percentage *per se*.

Inter-Colliery Comparisons of Dust Concentrations

The individual dust concentrations on which the averages given earlier are based vary over a wide range. At all collieries both low and quite high dust concentrations were observed. The standard errors of the individual means are given in Table XL, but the magnitude of the variations encountered is perhaps better illustrated by Table XLII, which shows the frequency of occurrence of various concentrations of the total dust. It will be clear that, with variations of the magnitude shown in this table, average values must differ substantially before the differences between them are of any significance. For both the total dust concentrations and the ash concentrations the differences between the averages for the various collieries have been tested pair by pair, and the results of these tests are shown in Tables XLIII, XLIV and XLV. Tables XLIII and XLIV show, for the total dust concentrations and the ash concentrations respectively, the differences between the various pairs of averages (excluding those for Colliery A.1) and the standard errors of those differences. In these tables, differences which are not less than twice their standard errors are shown in heavy type, to indicate that they are significant.

TABLE XLII

Frequency of occurrence of various concentrations of total dust

Colliery.	Number of samples.	Number of samples giving mass concentrations (mg. per cub. metre) :—											Median value : mg. per cub. metre.
		under 100.	100-199.	200-299.	300-399.	400-499.	500-599.	600-699.	700-799.	800-899.	900-999.	1,000 and over.	
A.1	8	—	—	1	1	—	1	1	1	1	—	2	728
A.6	50	—	4	8	11	11	6	3	3	1	2	1	407
A.3	71	6	12	12	8	8	4	4	2	3	4	8	370
A.8	58	4	5	7	10	7	5	5	2	2	3	8	439
S.3	82	6	20	23	13	9	5	3	3	—	—	—	251
B.1	61	7	22	10	11	3	4	1	—	—	—	3	229
S.5	62	10	18	10	11	6	2	2	3	—	—	—	228
A.2	85	17	15	6	13	7	4	6	3	2	2	10	363
S.4	78	19	26	16	6	3	2	1	2	—	2	1	163
B.3	115	79	22	7	4	2	1	—	—	—	—	—	53
B.2	46	13	13	5	5	3	2	1	1	—	—	3	167
A.5	64	6	12	17	10	4	3	5	1	—	3	3	274

TABLE XLIII

Differences (and their standard errors) between mean mass concentrations of total dust at different collieries : all samples

Colliery.	Mean mass concentration : mg. per cub. metre.	A.6.	A.3.	A.8.	S.3.	B.1.	S.5.	A.2.	S.4.	B.3.	B.2.	A.5.
		462.	535.	584.	296.	308.	273.	457.	243.	94.	287.	377.
A.6	462	—	—	—	—	—	—	—	—	—	—	—
A.3	535	73±80	—	—	—	—	—	—	—	—	—	—
A.8	584	122±72	49±97	—	—	—	—	—	—	—	—	—
S.3	296	166±38	239±75	288±67	—	—	—	—	—	—	—	—
B.1	308	154±53	227±83	276±77	12±45	—	—	—	—	—	—	—
S.5	273	189±40	262±76	311±69	23±30	35±47	—	—	—	—	—	—
A.2	457	5±59	78±88	127±81	161±53	149±64	184±55	—	—	—	—	—
S.4	243	219±42	292±77	341±70	53±32	65±49	30±35	214±56	—	—	—	—
B.3	94	368±34	441±73	490±65	202±21	214±42	179±25	363±50	149±28	—	—	—
B.2	287	175±56	248±86	297±79	9±50	21±62	14±51	170±67	44±53	193±47	—	—
A.5	377	85±51	158±83	207±76	81±44	69±57	104±46	80±63	134±48	283±41	90±61	—

TABLE XLIV

Differences (and their standard errors) between mean ash concentrations at different collieries : all samples

Colliery.	Mean ash concentration : mg. per cub. metre.	A.6.	A.3.	A.8.	S.3.	B.1.	S.5.	A.2.	S.4.	B.3.	B.2.	A.5.
		86.2.	61.4.	60.7.	40.2.	50.2.	28.6.	44.9.	25.7.	25.6.	54.0	42.0.
A.6	86.2	—	—	—	—	—	—	—	—	—	—	—
A.3	61.4	24.8±10.5	—	—	—	—	—	—	—	—	—	—
A.8	60.7	25.5±9.0	0.7±10.4	—	—	—	—	—	—	—	—	—
S.3	40.2	46.0±7.3	21.2±9.0	20.6±7.2	—	—	—	—	—	—	—	—
B.1	50.2	38.0±9.5	11.2±10.8	10.5±9.4	10.0±7.8	—	—	—	—	—	—	—
S.5	28.6	57.7±8.9	32.9±8.7	32.2±6.8	11.7±4.8	21.7±7.5	—	—	—	—	—	—
A.2	44.9	41.2±8.2	16.5±9.7	15.8±8.1	4.7±6.2	5.8±8.7	16.4±5.7	—	—	—	—	—
S.4	25.7	60.5±7.1	35.7±8.8	35.0±7.0	14.5±4.6	24.5±7.6	2.8±4.0	19.2±6.0	—	—	—	—
B.3	25.6	60.6±7.3	35.8±9.0	35.1±7.2	14.6±4.9	24.6±7.8	2.9±4.3	19.3±6.2	0.1±4.6	—	—	—
B.2	54.0	38.2±11.2	7.4±12.4	6.7±11.2	13.8±9.9	3.8±11.6	25.5±9.6	9.1±10.6	28.8±9.7	28.4±9.9	—	—
A.5	42.0	44.2±7.6	19.4±9.2	18.7±7.5	1.6±5.4	8.2±8.1	13.5±4.8	2.9±6.6	16.3±5.1	16.4±5.4	12.0±10.1	—

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Owing to the small number of observations at Colliery A.1, the usual method of ascertaining the standard error of the difference between means cannot be applied for the comparison of this colliery with others, and instead a calculation has been made of the probability that the differences observed between the average dust concentrations at Colliery A.1 and those for other collieries could have arisen by chance. These figures are given in Table XLV. Where the probability (*P*) is less than 0.05 the difference can be taken as significant.

(i) *Total Dust Concentrations.*—From Table XLV it can be seen that the average total dust concentration at Colliery A.1 does not differ significantly from the corresponding figures at Collieries A.3, A.8 and A.2, but that it does differ significantly from those at the remaining collieries. Thus, the anthracite mine with the highest incidence of pulmonary X-ray abnormalities has an average total dust concentration (based admittedly on few observations) which is significantly higher than the averages for the various steam and bituminous coalmines, and higher than those for another high incidence anthracite mine (A.6) and a low incidence anthracite mine (A.5). On the other hand, its average dust concentration is not significantly higher than that in another low incidence anthracite mine (A.2).

It may be objected that the eight observations made in the Main Bully at Colliery A.1 are too few for any sound conclusions, and that this colliery should be excluded from the discussion. In that case, the data given in Table XLIII may be considered. Amongst the five anthracite collieries there shown, the only pair at which the average total dust concentrations differ significantly are Collieries A.5 and A.8: in no other pair do the averages differ by more than twice the standard error of the difference.

It thus appears that within the anthracite area there is no real relationship between the incidence of pulmonary abnormalities and the mass concentration of the total dust, for in five collieries with widely varying incidences no substantial differences in dust concentration were found. In most cases the steam and bituminous coalmines have significantly lower total dust concentrations than the anthracite mines, and the significant correlations between

TABLE XLV

Significance of differences between dust concentrations at Colliery A.1 and at other collieries

Colliery.	Total dust concentration.			Ash concentration.		
	Mean (mg. per cub. metre).	Difference from A.1.	P.	Mean (mg. per cub. metre).	Difference from A.1.	P.
A.1	770	—	—	99.8	—	—
A.6	462	308	Less than 0.01	86.2	13.6	0.40-0.50
A.3	535	235	0.20-0.30	61.4	38.4	0.10-0.20
A.8	584	186	0.30-0.40	60.7	39.1	0.02-0.05
S.3	296	474	Less than 0.01	40.2	59.6	Less than 0.01
B.1	308	462	Less than 0.01	50.2	49.6	0.01-0.02
S.5	273	497	Less than 0.01	28.5	71.3	Less than 0.01
A.2	457	313	0.05-0.10	44.9	54.9	Less than 0.01
S.4	243	527	Less than 0.01	25.7	74.1	Less than 0.01
B.3	94	676	Less than 0.01	25.6	74.2	Less than 0.01
B.2	287	483	Less than 0.01	54.0	45.8	0.05-0.10
A.5	377	393	Less than 0.01	42.0	57.8	Less than 0.01

incidence and total dust reflect the fact that the steam and bituminous coalmines tend to have lower incidences and lower dust concentrations than the anthracite mines.

(ii) *Ash concentrations.*—Table XLIV shows that the average ash concentration at Colliery A.1 differs significantly from those at most of the other collieries. It does not differ significantly from the averages for Collieries A.6, A.3 and B.2.

From Table XLIII it can be seen that the average ash concentration at Colliery A.6 differs from the averages for each of the remaining collieries shown in that table. Indeed, it will be noticed that the various anthracite collieries differ substantially among themselves in their average ash concentrations, a lower ash concentration being associated with a lower incidence of pulmonary X-ray abnormalities in the colliers. On the whole, too, the steam and bituminous coalmines with their lower incidences of pulmonary disease have lower ash concentrations than the anthracite mines. The correlation is by no means perfect, however, for Colliery B.2, with its zero incidence, has a higher ash concentration than any of the other non-anthracite mines. Still, the differences noted in the table, considered together with the fact that the correlation of the incidence of pulmonary abnormalities with the ash concentration is in each case higher than the correlation with the total dust concentration, lead to the conclusion that the incidence of pulmonary abnormalities is related to the average ash concentration, and that the apparent relation between incidence and total dust is probably due to the fact that high ash concentrations tend to be associated with high total dust concentrations.

SUMMARY AND CONCLUSIONS

1. This report gives the results of an extensive study of the mass concentrations of air-borne dust, and of the minerals other than coal (ash) in that dust, at a number of collieries in South Wales. The naphthalene filter method of dust sampling was employed and is described.

In sampling, the dust was collected by drawing air through a filter of compressed naphthalene by means of a hand pump. Later, the naphthalene was sublimed by warming to 70°C. and the dust content of the sampled air was left as a residue and was weighed. The dust was then ignited at about 500°C. to burn away the carbon, and the ash was weighed. Thus, the mass concentrations of the whole dust and of the ash, and the percentage of ash in the dust, were determined.

2. Samples were taken at twelve collieries. Six of these were anthracite mines, three were in the bituminous area of the coalfield, and the remaining three produced steam coal. The number of samples at any colliery depended on the size and lay-out of the colliery: an endeavour was made in each case to obtain sufficient samples to give a true picture of the varying concentrations of dust to which the collier was exposed during the working shift. Altogether, about 800 samples were taken, and the data derived from these have been subjected to statistical examination.

3. It was of practical interest to determine how far the dust created by ripping operations differed from that produced by coalgetting, and handling. The one clear conclusion on this point is that while ripping is being done, or rippings handled, the percentage ash content of the dust is substantially higher than when the men are working in coal. Such effect as there is on the mass concentration of the total dust tends to be in the direction that there is more dust during coalhandling than during ripping. There seems to be some tendency for the higher ash concentrations to occur during ripping, but this relation does not hold at all the collieries.

4. In relating the dust determinations to the medical findings, a major difficulty lies in the fact that, whereas the dust measurements have all been made in the last year or two, the pulmonary abnormalities found in the medical survey have been contracted over a period of many years, and precise knowledge

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of the nature and concentration of the dust actually responsible for those abnormalities is not available. The extent to which the results now obtained may serve as indices of former working conditions is discussed.

5. The relationship between the incidence of pulmonary X-ray abnormalities at the different collieries and the averages of the dust and ash concentrations, and of the ash percentages, observed at those collieries has been tested by calculating correlation coefficients, and by examining the significance of the differences between the observed average dust figures for the various collieries.

It has been shown that the incidence of pulmonary abnormalities is significantly and positively correlated with the average ash concentration. High ash concentrations tend to be associated with high total dust concentrations, and, probably on that account, there is an apparent correlation between incidence and total dust concentration. It is concluded, however, that this latter relationship is only apparent, and that there is no independent association between incidence and total dust concentration. It appears that the incidence of chronic pulmonary disease is not related to the ash percentage *per se*.

ACKNOWLEDGMENTS

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CHRONIC PULMONARY DISEASE IN SOUTH WALES COALMINERS—II. ENVIRONMENTAL STUDIES

D.—THE COMPOSITION OF THE AIR-BORNE DUSTS AT THE COAL-FACE IN CERTAIN MINES*

BY

G. NAGELSCHMIDT, D.Phil.

(Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts).

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PART I. GENERAL

INTRODUCTION

In the report on the medical part of this investigation (*Spec. Rep. Ser. Med. Res. Coun., Lond.*, No. 243, 1942) the varying incidence of pulmonary abnormalities amongst miners in the South Wales coalfield is described. The incidence is shown to be higher in the anthracite than in the non-anthracite area, and there is also wide variation between different anthracite mines. The main environmental factor to be studied in relation to the pulmonary abnormalities is the air-borne dust in the mines. The concentration of the dusts is fully dealt with by other contributors to this symposium, and the present report is concerned with the composition of the dusts, with the object of detecting any relation which this may bear to the incidence of pulmonary abnormalities. Dust composition is assessed chiefly from chemical and mineralogical analyses and from grain size measurements. Since the pulmonary abnormalities are mainly found amongst colliers, the samples for analysis have been taken so as to represent, as far as possible, the dust breathed at the coalface.

* The dust samples discussed in this report were collected by Drs. P. F. Holt and N. L. Spoor under the direction of Professor H. V. A. Briscoe. Chemical analyses of the dusts and their ashes were made by Geochemical Laboratories, London and X-ray diffraction analyses by the Physics Department of the National Physical Laboratory, and by the author. The grain-size distributions of certain dusts were determined microscopically by Dr. T. Bedford and Dr. C. G. Warner, who also made similar determinations upon the quartz separated from some of the dusts by Dr. E. J. King. The quartz content of ten of the dust ashes was determined by "rational analysis" by Mr. A. Shaw, Mining Research Laboratory. The coal part of some of the dusts was analysed chemically by Mr. D. Hicks and the staff of the Coal Survey Laboratory, Cardiff, and microscopically by Dr. C. A. Seyler. In compiling this report, the writer had the active collaboration of all these investigators, and of Dr. A. Brammall and Dr. P. D'Arcy Hart.

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In their medical survey, Hart and Aslett classified the 16 South Wales collieries investigated according to the incidence of pulmonary X-ray abnormalities amongst the colliers, and they grouped them broadly into "high", "medium", "low-medium", and "low" incidence mines. For the present study, 23 dust samples have been collected from 12 of these 16 mines, as shown below:—

Distribution of 23 dust samples in relation to rank of coal and to incidence of pulmonary X-ray abnormalities among the colliers at the mines sampled

Incidence of pulmonary X-ray abnormalities.	Rank of coal			
	Anthracite.	Steam coal.	Bituminous coal.	All.
High ..	3 (7)	—	—	3 (7)
Medium ..	1 (1)	1 (1)	—	2 (2)
Low-medium ..	—	1 (1)	1 (1)	2 (2)
Low ..	2 (6)	1 (2)	2 (4)	5 (12)
All ..	6 (14)	3 (4)	3 (5)	12 (23)

Unbracketed figures show the number of mines sampled; bracketed figures show the number of dust samples.

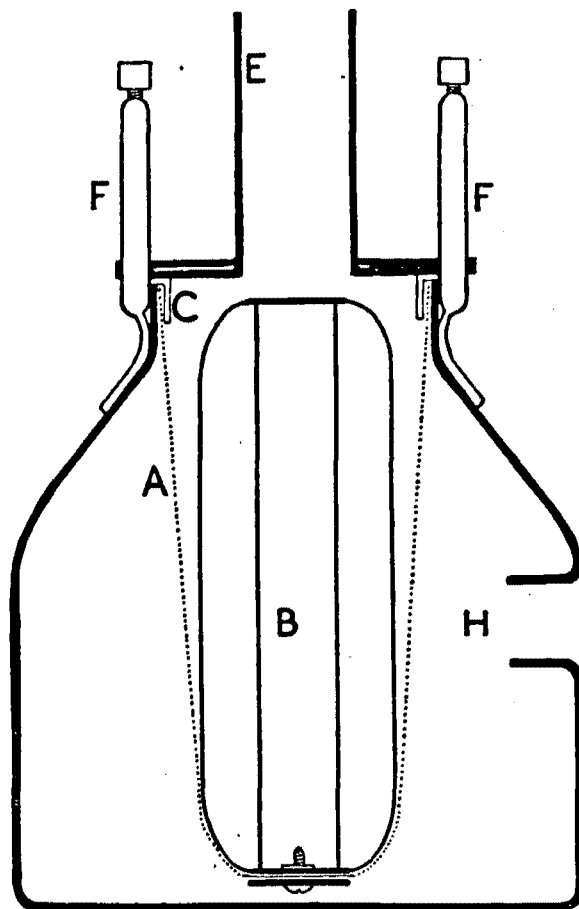
In addition, two dust samples were secured from a bituminous coalmine not investigated medically. The seam worked at this mine was the Red Ash at the base of the Pennant Coal Series (unlike all the other mines, in which seams belonging to the Lower Coal Series were investigated), and the roof was sandstone. At this mine the incidence of certified silicosis was one of the highest in the coalfield.

It should be noted that stone-dusting of the underground roadways up to the coalface is general in all non-anthracite mines in South Wales. In the present series, at the time of sampling, shale was used as the dusting material in four mines, and limestone in three.

SAMPLING TECHNIQUE AND DETAILS OF COLLECTION OF THE DUSTS

The samples were collected in a fabric bag filter, which was mounted on a wire frame inside a metal container. The general arrangement of this apparatus, adapted from a "Tellus" vacuum cleaner, is shown in Fig. 12. The cloth bag A, 10 in. long and 5 in. in diameter, is tied to an iron ring C, which is rigidly clamped in a rubber gasket between the nickel-plated can and a copper adapter E, by means of two fasteners F. The other end of the bag is drawn together and screwed between a metal disc and the loose wire frame B, which keeps the bag from collapsing when the filter is in operation. The bag consists of two thicknesses of "Tricoline", a closely-woven cotton material, which is found to provide a strong, efficient, and convenient form of filter. In use, the adapter, E, is connected by means of stout radiator hose to either a compressed-air ejector or a hand-operated fan, suction thus being applied to the inside of the bag. Air is sucked through the inlet hole H, and the air-borne dust is deposited on the outside surface of the fabric. When the filter is not in use, the hole is stopped with a rubber bung. The ejector used for the collection of most of the samples was fitted with an $\frac{1}{8}$ in. jet, and was connected to a compressed-air supply giving a pressure of about 60 lb. per square inch.

The filter was placed at the side of the stall road or coal heading, or next to the gob (the space previously occupied by the coal and now by rock debris); it was situated at a distance of between 6 and 12 feet from the coalface, in such direction as to receive the stream of air laden with dust produced by the various operations in the particular working place. When the filter was



A. Tricoline bag. B. Wire frame. C. Iron ring. E. Copper adapter.
 F. Fastener. H. Inlet Hole.

FIG. 12.—Dust sampling apparatus.

used in connection with the compressed-air ejector, the filter and ejector were fastened together to a stout wooden frame, which was suspended from a prop near the face. At some collieries compressed air could not be made available at the position selected for the collection of the sample, and then the necessary suction was produced by means of a hand-operated fan made for the purpose. In this case, the filter was fixed in a suitable position near the face and connected by a length of hose to the fan, which could be operated more conveniently in the roadway about 10 feet away. The filter was invariably shifted forward once or twice a week, so that the sample should always be collected near the advancing coalface.

All the samples were collected during the coalgetting shifts only, and each is assumed to be representative of the air-borne dust produced by the various operations carried out during that shift by the collier; these operations include faceripping as well as actual coalgetting. The filter was usually left in operation over a period of between 10 and 30 days. At the end of this time the sample was passed through a standard 300 mesh sieve, in order to remove any large pieces of coal or rock that might accidentally have entered the filter. Some collieries work two coalgetting shifts, and in such cases the filter was left to operate over both shifts.

TABLE XLVI
Particulars of dust samples collected in 13 South Wales mines

Rank of coal.	Colliery.	Sample No.	Seam.	District.	Working place.	Shift.	Method of collection.	Stone dust used.
Anthracite	A.1	2M1	Lower Pumpquart ..	Douglas	Stall.. ..	M	C	—
	A.1	2M2	Lower Pumpquart ..	Main Bully ..	Stall.. ..	M	C	—
	A.2	1S1	Lower Pumpquart ..	11	Tophole ..	M	H	—
	A.2	2S1	Lower Pumpquart ..	5	Stall.. ..	M	H	—
	A.2	2S2	Lower Pumpquart ..	5	Tophole ..	M	H	—
	A.3	2H1	Stanlyd	28	Stall.. ..	M	C	—
	A.3	2H2	Stanlyd	94	Stall.. ..	M	C	—
	A.3	3H1	Stanlyd	28	Stall.. ..	M	C	—
	A.5	1D1	Red Vein	Dan Griffith ..	Stall.. ..	M	H	—
	A.5	1D2	Red Vein	Dan Griffith ..	Stall.. ..	M	H	—
	A.5	1D3	Red Vein	Bully Aaron's ..	Stall.. ..	M	H	—
	A.6	2R1	Red Vein	" N. Lower " ..	Conveyor ..	M	C	—
	A.6	2R2	Red Vein	" O "	Conveyor ..	M	C	—
	Steam coal	A.8	2N1	Nine Foot	West	Stall*	M	H
S.3		1E1	Six Foot .. ..	.. ..	" Barry " ..	M & N	C	S
S.4		1U1	2-ft. 9-in. .. ..	.. ..	Stall.. ..	M	C	S
S.4		2U1	3-ft. 10-in.	South	Stall.. ..	M & N	C	S
S.5		1T1	Lower 5 Foot .. ..	.. ..	Stall.. ..	M	C	S
Bituminous coal ..	B.1	1A1	Rhas Las	Parr's	Stall.. ..	M	C	S
	B.6	1A2	Red Ash	No. 7 Heading ..	Heading	M	C	S
	B.6	1A3	Red Ash	Intake Side, No. 7 Heading.	Stall.. ..	M	C	S
	B.2	1C1	Black Vein	W. Side	Stall.. ..	M & A	C	S
	B.3	1B1	Black Vein	R. Watkins' Place, Return Side.	Stall.. ..	M	H	L
	B.3	1B2	Meadow Vein	M.1	Stall.. ..	M	H	L
	B.3	1B3	Meadow Vein	North C:2	Stall.. ..	M	H	L

* The method of mining is longwall stalls, except in colliery A.8, where it is pillar and stall working
M = Morning. A = Afternoon. N = Nights. C = Compressed air ejector. H = Hand-operated fan. S = Shale dusting. L = Limestone dusting.

The object in collecting these samples was to obtain air-borne dust for chemical and mineralogical analysis, and as any measurement of the quantity of air filtered over such a long period would have been very difficult, no attempt was made to determine the mass concentration of air-borne dust from the weight of the samples collected. The weight varied from 30 to 200 gms. Table XLVI shows in detail the particulars of collection of the 25 samples investigated, including seams, districts and working places, and—for the non-anthracite mines—the material used for stone dusting. The colliery code numbers are the same as those used in the medical report, except for the additional mine, B.6.

THE PARTICLE-SIZE DISTRIBUTION OF THE DUSTS

The size distribution of the particles in the dust samples was determined by microscopic examination of 14 samples from 8 of the mines. In preparing slides for examination, a very small amount of dust was taken up on the pointed end of a glass rod and transferred to a clean slide. Then a cover glass was placed on the slide, and, by light pressure of the finger, the cover glass was gently rubbed over the slide with a rotary motion, the deposit of dust thus being spread into a light smear in which the particles were for the most part easily countable. Any occasional large aggregations of particles were ignored. From each sample three such slides were prepared, and approximately equal numbers of particles were measured on each slide of a given sample. It was found that the size distributions derived from the three slides from any sample corresponded very closely.

The slides were examined under the microscope with a 2 mm. apochromatic oil-immersion objective and a $\times 15$ eyepiece. Illumination was by a 100 c.p. Pointolite lamp, and the light was passed through a blue-green filter. A special eyepiece graticule, described by Patterson and Cawood (1936), was used in measuring particle sizes. Visual discrimination was made between particles of coal and of minerals other than coal down to a particle size of 0.4 micron. Between 1,000 and 1,500 particles were measured from each sample.

Table XLVII shows the percentage particle size distribution in the different samples. Little stress can be laid on any differences thus shown between the various samples, for in each case the dust consists of the two distinct fractions—coal and other minerals. It is better to treat each of these fractions separately.

In Table XLVIII the percentages shown in Table XLVII are subdivided to give the percentages of the total number of particles measured which represent coal or other mineral particles of any given size. Thus, for sample 2M1, Tables XLVII and XLVIII A show that 74.5 per cent. of the total visible particles were of 0.4 micron or greater size, and that of these 53.0 per cent. were coal particles and 21.5 per cent. minerals other than coal. The percentages of the coal particles in nine size groups are shown in Table XLVIII B, and those of the non-coal particles in Table XLVIII C.

As can be seen from Tables XLVIII B and C, only a negligible number of the non-coal particles exceeded 5 microns in size, but a fair number of the coal particles were larger than that. The measured sizes of the coal particles larger than 5 microns are given in Table XLIX. To take sample 2M1 again: of the total particles viewed, 1.5 per cent. were coal particles larger than 5 microns; this proportion of the total particles was accounted for by 10 particles of 6 microns diameter, 1 of 8 microns, and 1 of 10 microns.

For comparison with the size distributions of the quartz particles to be given later (p. 112), it is desirable that the size distributions of the non-coal particles in the air-borne dust samples should be expressed as percentages of the numbers of such particles measured. This information is given in Table L, where the number of particles measured within each size group is expressed as a percentage of the number of particles of minerals other than coal of 0.4 micron or greater size.

TABLE XLVII

Percentage particle size distributions of 14 dusts

Colliery.	Sample.	Percentage of dust particles of size (microns) :—										
		under 0·2.	0·2- 0·4.	0·4- 0·8.	0·8- 1·2.	1·2- 1·6.	1·6- 2·0.	2·0- 2·5.	2·5- 3·0.	3·0- 4·0.	4·0- 5·0.	over 5·0.
A.1	2M1	12·1	13·4	26·1	16·7	10·0	4·9	4·1	4·6	3·8	2·8	1·5
A.2	1S1	10·6	12·8	29·5	16·3	9·7	7·9	4·6	2·7	3·5	1·5	0·9
A.2	2S1	4·0	7·1	26·4	20·9	15·7	7·4	5·2	4·8	4·7	2·3	1·5
A.2	2S2	4·9	9·1	23·9	21·4	14·8	9·7	3·7	3·7	4·7	2·2	1·9
A.3	2H1	9·1	11·7	23·4	19·5	9·8	7·9	5·1	3·2	4·9	3·2	2·2
A.3	2H2	9·7	11·3	24·9	18·5	9·7	8·4	5·5	2·9	4·8	2·2	2·1
A.3	3H1	6·5	7·9	29·9	17·4	12·8	7·6	4·3	4·2	4·3	1·8	3·3
S.4	1U1	10·3	13·5	31·6	17·4	9·2	4·7	3·9	2·7	3·0	2·5	1·2
S.4	2U1	5·2	6·6	23·5	21·6	15·9	10·3	3·9	5·7	4·3	2·0	1·0
S.5	1T1	11·4	16·4	26·8	14·7	9·7	5·9	4·0	2·9	3·1	2·8	2·3
B.6	1A2	5·0	10·3	30·7	21·2	12·2	7·1	3·1	3·7	2·7	1·8	2·2
B.2	1C1	9·8	12·4	23·1	18·5	12·0	8·4	4·4	3·3	3·6	2·4	2·1
B.3	1B1	8·2	8·5	21·5	18·6	17·7	10·3	4·8	2·4	4·0	2·3	1·7
B.3	1B2	7·0	8·3	16·0	18·3	20·5	11·3	7·1	4·0	3·7	1·7	2·1

The main conclusion from the microscopic counts was that most of the particles—including over 99 per cent. of the non-coal particles—were of respirable size, but that neither the whole dusts nor the non-coal fractions showed clear differences as between anthracite and non-anthracite.

TABLE XLVIII A

Particle size distributions of 14 dusts, showing numbers of coal and of non-coal particles of 0.4 micron or greater size, expressed as percentages of total particles measured

Colliery.	Sample.	Percentage of total visible particles of 0.4 micron or greater size.	All coal particles of 0.4 micron and over.	All non-coal particles of 0.4 micron and over.
A.1	2M1	74.5	53.0	21.5
A.2	1S1	76.6	61.8	14.8
A.2	2S1	88.9	56.9	32.0
A.2	2S2	86.0	55.0	31.0
A.3	2H1	79.2	58.9	20.3
A.3	2H2	79.0	60.5	18.5
A.3	3H1	85.6	49.4	36.2
S.4	1U1	76.2	47.6	28.6
S.4	2U1	88.2	47.2	41.0
S.5	1T1	72.2	43.8	28.4
B.6	1A2	84.7	51.0	33.7
B.2	1C1	77.8	43.0	34.8
B.3	1B1	83.3	37.0	46.3
B.3	1B2	84.7	37.8	46.9

TABLE XLVIII B

Colliery.	Sample.	Percentage of total dust particles counted represented by								
		coal particles of size (microns) :—								
		0.4-0.8.	0.8-1.2.	1.2-1.6.	1.6-2.0.	2.0-2.5.	2.5-3.0.	3.0-4.0.	4.0-5.0.	5.0 and over.
A.1	2M1	17.6	10.6	6.5	4.3	3.3	3.6	3.4	2.2	1.5
A.2	1S1	22.4	12.5	8.2	7.2	4.1	2.4	2.8	1.3	0.9
A.2	2S1	11.1	13.0	10.4	6.0	4.0	4.0	4.6	2.8	1.5
A.2	2S2	9.9	12.2	10.2	7.9	3.3	2.9	4.5	2.2	1.9
A.3	2H1	16.4	12.9	7.3	6.4	3.9	2.5	4.3	3.1	2.1
A.3	2H2	18.7	13.5	7.7	7.4	4.5	2.5	4.1	2.1	2.0
A.3	3H1	9.0	8.9	9.0	6.0	3.4	3.8	4.2	1.8	3.3
S.4	1U1	15.0	10.0	6.5	4.0	3.6	2.4	2.6	2.5	1.0
S.4	2U1	5.7	10.0	9.2	7.3	3.0	4.7	4.3	2.0	1.0
S.5	1T1	12.0	7.0	6.5	4.5	3.6	2.7	2.6	2.6	2.3
B.6	1A2	13.2	11.3	8.3	5.6	3.0	3.0	2.7	1.7	2.2
B.2	1C1	7.1	9.0	7.6	5.6	3.7	3.0	2.8	2.3	1.9
B.3	1B1	6.7	6.6	7.5	4.7	2.9	1.3	3.4	2.2	1.7
B.3	1B2	5.1	6.6	8.1	5.6	3.9	2.0	2.9	1.5	2.1

TABLE XLVIII C

Colliery.	Sample.	Percentage of total dust particles counted represented by								
		non-coal particles of size (microns) :—								
		0.4-0.8.	0.8-1.2.	1.2-1.6.	1.6-2.0.	2.0-2.5.	2.5-3.0.	3.0-4.0.	4.0-5.0.	5.0 and over.
A.1	2M1	8.5	6.1	3.5	0.6	0.8	1.0	0.4	0.6	—
A.2	1S1	7.1	3.8	1.5	0.7	0.5	0.3	0.7	0.2	—
A.2	2S1	15.8	7.9	5.3	1.4	1.2	0.8	0.1	—	—
A.2	2S2	14.0	9.2	4.6	1.8	0.4	0.8	0.2	—	—
A.3	2H1	7.0	6.6	2.5	1.5	1.2	0.7	0.6	0.1	0.1
A.3	2H2	8.2	5.0	2.0	1.0	1.0	0.4	0.7	0.1	0.1
A.3	3H1	20.9	8.5	3.8	1.6	0.9	0.4	0.1	—	—
S.4	1U1	16.6	7.4	2.7	0.7	0.3	0.3	0.4	—	0.2
S.4	2U1	17.8	11.6	6.7	3.0	0.9	1.0	—	—	—
S.5	1T1	14.8	7.7	3.2	1.4	0.4	0.2	0.5	0.2	—
B.6	1A2	17.5	9.9	3.9	1.5	0.1	0.7	—	0.1	—
B.2	1C1	16.0	9.5	4.4	2.8	0.7	0.3	0.8	0.1	0.2
B.3	1B1	14.8	12.0	10.2	5.6	1.9	1.1	0.6	0.1	—
B.3	1B2	10.9	11.7	12.4	5.7	3.2	2.0	0.8	0.2	—

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TABLE XLIX

Sizes of coal particles of diameter greater than 5 microns in 14 dusts

Colliery.	Sample.	Number of coal particles greater than 5 microns as percentage of total particles.	Number of coal particles measured at sizes (microns) :—					
			6.	8.	10.	15.	20.	30.
A.1	2M1	1.5	10	1	1	—	—	—
A.2	1S1	0.9	12	—	—	—	—	—
A.2	2S1	1.5	8	4	—	—	—	—
A.2	2S2	1.9	14	1	—	—	—	—
A.3	2H1	2.1	24	2	7	—	—	—
A.3	2H2	2.0	25	1	5	—	—	—
A.3	3H1	3.3	13	8	3	—	1	1
S.4	1U1	1.0	9	1	—	—	—	—
S.4	2U1	1.0	7	1	—	—	—	—
S.5	1T1	2.3	15	2	1	—	—	—
B.6	1A2	2.2	9	7	1	—	—	—
B.2	1C1	1.9	13	2	2	—	—	—
B.3	1B1	1.7	13	1	2	—	—	—
B.3	1B2	2.1	14	3	2	—	—	—

TABLE L

Size distributions of non-coal fractions of 14 dusts, expressed as percentages of total number of non-coal particles of 0.4 micron or greater size

Colliery.	Sample.	Number of particles of various sizes (microns) as percentage of total number of particles of 0.4 micron or greater size .—									Total.
		0.4-0.8.	0.8-1.2.	1.2-1.6.	1.6-2.0.	2.0-2.5.	2.5-3.0.	3.0-4.0.	4.0-5.0.	over 5.	
A.1	2M1	39.4	28.2	16.5	3.0	3.5	4.7	1.8	2.9	—	100.0
A.2	1S1	47.7	25.8	10.0	5.0	3.0	2.0	5.0	1.5	—	100.0
A.2	2S1	47.8	24.7	16.6	4.5	3.6	2.4	0.4	—	—	100.0
A.2	2S2	45.0	29.8	14.9	5.8	1.2	2.5	0.8	—	—	100.0
A.3	2H1	34.7	32.8	12.2	7.4	5.8	3.2	2.9	0.7	0.3	100.0
A.3	2H2	44.0	27.1	10.9	5.3	5.6	2.1	3.9	0.7	0.4	100.0
A.3	3H1	57.7	23.4	10.5	4.6	2.5	1.0	0.3	—	—	100.0
S.4	1U1	57.9	26.0	9.6	2.4	1.0	1.0	1.4	—	0.7	100.0
S.4	2U1	43.4	28.3	16.3	7.4	2.1	2.5	—	—	—	100.0
S.5	1T1	51.8	27.0	11.2	5.0	1.4	0.9	1.8	0.9	—	100.0
B.6	1A2	51.9	29.4	11.4	4.2	0.4	2.3	—	0.4	—	100.0
B.2	1C1	45.8	27.3	12.7	8.1	1.9	1.0	2.3	0.3	0.6	100.0
B.3	1B1	31.9	25.8	22.1	12.2	4.0	2.4	1.4	0.2	—	100.0
B.3	1B2	23.4	25.0	26.4	12.0	6.7	4.4	1.6	0.5	—	100.0

PART II.—CHEMICAL AND MINERALOGICAL COMPOSITION OF THE DUSTS**COAL FRACTION**

Most of the work described in this report deals with the inorganic constituents of the dusts, but a few microscopic and chemical tests were made in order to ascertain whether the coal in the dusts is similar to that in the seams or whether it contains a noticeable concentration of any particular constituent, such as fusain.

The South Wales coal seams are comparatively homogeneous when considered in terms of the petrographic constituents durain, vitrain, clarain and fusain. The seams consist chiefly of clarain interspersed with thin streaks of vitrain. In some of the bituminous coals containing a high proportion of volatile matter, particularly those with less than 88 per cent. of carbon, there are occasional thin bands of dull coal which can be described as durain; but in the South Wales coals which contain more than 88 per cent. of carbon, bands of durain have not been found, except very occasionally in some of the anthracites. The amount of fusain in the South Wales coals represents a small percentage of the total coal substance. Some seams over a large part of the field contain little or no fusain—for example, the Nine Feet Seam and its equivalents, which contain usually less than 1 per cent. Some of the other seams contain up to 10 per cent., and frequently the fusain is found in well-defined horizons in a seam, e.g., the Lower Pumpquart in the bottom 12 in. and in a narrow band about 18 in. from the floor, the remainder of the seam being bright vitrainous coal.

Comparisons of the coal in the air-borne dusts with the corresponding coal from the seams are complicated by the fact that both microscopic and chemical analyses of the coal in the dusts are difficult. Two of the samples were examined microscopically and compared with average samples of the seam at the respective collieries. The same petrographic constituents were found in the dusts as in the whole-seam samples, and there did not seem to be any striking difference in the concentration of any constituent. There was probably slightly more vitrain in the dusts than in the whole-seam samples; this would be in accordance with the greater fragility of the vitrain.

The percentages of carbon and hydrogen in the coal substance of four of the dusts were determined chemically and found to be of the same order as those in the corresponding whole-seam samples. These results do not suggest any noteworthy concentration of fusain in the air-borne dusts, as in that case the percentages of hydrogen in the dust coal would have been much less than those in the seam coal.

Although the microscopic and chemical tests outlined above were neither comprehensive nor very accurate, they do indicate that the coal in the dust is very similar to the coal in the whole seam. It cannot be argued, therefore, that any conclusions based on differences in the coal or its mineral matter from mines with a high and low incidence of pulmonary disease would be invalid because such differences would not apply to air-borne dusts.

NON-COAL FRACTION

For studies of the composition of the non-coal fraction the dusts were ashed at 380°C*. The ash was found to be a mixture of several minerals which could

* It is possible to isolate some, but not all, of the non-coal constituents of the dusts by flotation or gravity separation. The remainder can be isolated from the coal only by ashing. It would have been possible to analyse these two non-coal fractions separately, but nothing is known about their relative importance as harmful substances in the lungs, and all analytical work would have had to be doubled. It was, therefore, decided to study the non-coal fraction after ashing at 380°C., although this may produce certain changes in the mineral content, such as oxidation of sulphides to sulphates or oxides, dehydration of hydroxides and decomposition of carbonates.

The comparatively low temperature of 380°C. was chosen in order not to destroy the crystal structure of any member of the kaolin group that might occur in the dusts.

be identified by X-ray diffraction analysis. Chemical analyses of the ash were made, and, from the results in conjunction with those of the X-ray diffraction work, the amounts of the different minerals in the ash and in the dusts were calculated. Quartz was found in all but one of the dusts; as this mineral is of special importance in connection with silicosis, it was isolated from a number of dusts, and its grain-size distribution determined microscopically. Direct quartz determinations by rational analysis were also made for several of the dusts.

(a) *Ash Percentage, X-ray Diffraction and Chemical Analysis*

Material for analysis was obtained by ashing the dusts in an electric muffle at a temperature not exceeding 380°C. The ash, as a percentage of the air-dried dusts, is shown in the first row of Table LI. It varies from 6 to 52 per cent., and the mean value for all the dusts is 18 per cent. Stone dusting, practised in the non-anthracite mines only, seems to increase the ash percentage, as the mean for all anthracite dusts is 13·3 per cent., whereas the mean for all non-anthracite dusts is 23·5 per cent. An alternative explanation would be that the non-anthracite seams contain more dirt bands, and therefore more ash, than the anthracite.

X-ray diffraction analysis can be considered as a substitute for microscopic analysis for mineral particles too small to be examined with the petrological microscope. The technique has been described for clay minerals by Nagelschmidt (1934, 1941), and full experimental details for one mine dust, 2H2 of the present series, have been given by Nagelschmidt & King (1941). Powder diagrams were taken of all samples and aggregate diagrams of a few of them. Powder diagrams of all dust ashes were also taken after a short treatment with *N.HCl*, to remove the carbonates which were present in most samples. These diagrams contained fewer lines and could, therefore, be used with greater precision to identify the siliceous minerals—quartz, mica and kaolin—the diagrams of which are not affected by the acid treatment.

In addition to identifying the various minerals, it is possible to make rough estimates of their amounts from the relative intensities of their diffraction lines. The estimates for "high", "medium", "low", etc., in Table LI are derived from visual comparisons of the relative intensities of the diffraction lines characterising the various minerals; the estimates of the carbonates and of hematite (Fe_2O_3) from diagrams of the untreated ash, those of the siliceous minerals from diagrams of the acid-treated ash. The lower limit of detection is about 2 per cent. for quartz, but for mica and kaolin it is higher. (With the aid of photometric equipment and further refinements in technique, quantitative mineral determinations can be made by X-ray diffraction analysis, as has been shown by Clark and Reynolds (1936) for the measurement of the amount of quartz in mine dusts; in the present inquiry, however, such photometric equipment was not available.)

The results of the X-ray diffraction analyses are shown in the lower part of Table LI. It will be seen that "kaolin" and "mica" were found in all the dust ashes, and quartz in all but one of them. It should be explained that the terms "kaolin" and "mica" here refer to minerals of the kaolin and mica groups respectively; each of these groups contains several closely related minerals, which can be distinguished only if they occur as sufficiently large particles. With the present dust ashes it was not possible to make such closer indentifications with certainty, but the member of the kaolin group may have been the mineral kaolinite, while the member of the mica group may, at least in part, have been illite. "Illite" is the name given by Grim, Bray and Bradley (1937) to a micaceous constituent isolated from Illinois shales and clays. The terms "sericite" or "hydrous muscovite" may refer to the same kind

TABLE LI
Chemical and X-ray diffraction analyses of 25 dusts

Rank of coal	Anthracite													
	High A.1		Low A.2			High A.3			Low A.5			High A.6		Medium A.8
Incidence of pneumoconiosis Colliery	2M1	2M2	1S1	2S1	2S2	2H1	2H2	3H1	1D1	1D2	1D3	2R1	2R2	2N1
Sample	2M1	2M2	1S1	2S1	2S2	2H1	2H2	3H1	1D1	1D2	1D3	2R1	2R2	2N1
<i>Per cent. of air-dried dust—</i>														
380°C. ash	17.2	13.5	7.5	16.3	8.9	18.2	15.1	10.2	12.9	11.3	8.7	18.6	18.8	8.3
Carbon dioxide	1.72	1.28	N.D.	1.38	1.65	N.D.	0.50	0.35	N.D.	1.03	0.14	0.88	0.87	0.56
Sulphur (H ₂ S)	0.01	trace	N.D.	trace	trace	N.D.	nil	0.01	N.D.	0.01	trace	0.01	0.01	nil
Sulphur (SO ₂)	N.D.	0.10	N.D.	nil	nil	N.D.	N.D.	0.02	N.D.	0.03	0.07	0.01	0.02	0.06
<i>Per cent. of 380°C. ash—</i>														
SiO ₂	40.28	37.58	38.0	41.02	24.01	41.1	47.88	42.66	37.12	34.63	37.62	44.27	45.69	39.76
Al ₂ O ₃	18.87	22.06	28.9	22.36	16.35	23.8	31.60	31.71	24.89	24.97	27.53	28.51	27.43	32.69
Fe ₂ O ₃	8.62	11.47	7.5	10.25	14.16	3.9	3.87	5.23	10.34	9.11	8.57	6.05	6.46	4.12
MgO	3.34	3.50	2.4	3.53	6.28	1.0	1.40	1.32	2.39	N.D.	2.16	1.93	1.87	1.68
CaO	6.49	6.29	4.7	5.64	12.61	5.9	3.08	4.15	6.96	N.D.	5.84	3.24	2.81	5.34
Na ₂ O	1.47	1.25	1.1	0.77	0.80	1.2	1.03	0.54	1.20	1.14	0.82	0.90	0.59	0.96
K ₂ O	2.13	1.90	1.7	2.62	0.71	2.3	1.58	1.32	1.75	1.33	1.36	3.10	3.13	1.22
H ₂ O+	N.D.	3.78	N.D.	5.54	4.43	7.9	4.55	6.28	4.53	} 16.22		4.03	5.28	4.44
H ₂ O-	1.27	2.28	0.6	1.92	2.85	1.2	0.66	1.41	1.77	} 3.02		1.56	0.78	1.75
TiO ₂	0.66	0.70	0.5	0.37	0.27	0.7	0.78	0.65	0.81	0.77	0.88	0.68	1.64	0.43
CO ₂	6.87	5.59	N.D.	3.17	11.13	N.D.	0.77	2.31	3.48	N.D.	3.90	2.54	2.45	3.87
SO ₂	4.24	4.24	N.D.	2.40	7.06	N.D.	2.16	1.94	5.38	N.D.	4.27	2.31	2.49	2.42
94.24 100.64 85.4 99.59 100.66 89.0 99.36 99.52 100.62 88.17 100.00 100.37 99.78 100.35														
<i>X-ray diffraction analyses—</i>														
Quartz	H/M	H/M	L	H/M	M	M	M	L	M	M	M	M	M	nil
Mica	L	L	L	L	V.L	M	L	V.L	L	V.L	V.L	M/L	M	V.L
Kaolin	M	M/L	H	M	H/M	H/M	H/M	H	M	H/M	H/M	M	M	H
Calcite	—	—	—	—	—	M	—	—	—	—	L	—	—	—
Ankerite or dolomite	M	M	M	H/M	H	—	V.L	L	M	M	M	M	M	M
Hematite	—	—	—	—	—	—	—	—	L	L	M	L	L	—

N.D. = not determined. H = high. M = medium. L = low. V.L. = very low

COMPOSITION OF THE AIR-BORNE DUSTS

TABLE LI—(continued).
Chemical and X-ray diffraction analyses of 25 dusts

Rank of coal	Steam coal					Bituminous coal						
	Medium S.3	Low S.4		Low- medium S.5	Low- medium B.1	— B.6		Low B.2	Low B.3			
		1E1	1U1	2U1	1	1A1	1A2	1A3	1C1	1B1	1B2	1B3
<i>Per cent. of air-dried dust—</i>												
380°C. ash	19.8	13.0	18.8	20.7	13.8	8.2	5.8	21.0	38.0	46.6	52.5	
Carbon dioxide	0.88	1.01	1.01	2.46	0.63	0.33	0.52	0.46	2.96	13.63	11.39	
Sulphur (H ₂ S)	0.01	0.35	nil	N.D.	trace	trace	trace	nil	trace	0.01	0.01	
Sulphur (SO ₂)	0.34	N.D.	0.07	N.D.	0.04	0.16	0.05	0.10	0.52	0.20	0.62	
<i>Per cent. of 380°C. ash—</i>												
SiO ₂	46.13	49.04	48.00	38.16	46.49	42.46	24.73	51.16	41.63	15.10	24.46	
Al ₂ O ₃	25.56	22.06	25.64	19.20	27.62	17.55	17.66	28.58	23.89	8.62	12.13	
Fe ₂ O ₃	3.77	6.00	2.48	2.07	4.96	17.69	25.51	3.02	3.22	2.44	3.48	
MgO	1.36	1.37	0.42	0.10	1.66	1.89	3.50	1.24	1.45	1.12	1.59	
CaO	5.59	5.03	6.20	15.65	3.65	3.60	8.05	2.14	10.29	38.62	28.18	
Na ₂ O	0.57	0.49	2.20	0.47	0.53	0.96	0.38	0.82	0.49	0.35	0.42	
K ₂ O	3.17	2.84	2.53	2.28	2.32	2.82	1.91	3.65	3.25	0.99	1.62	
H ₂ O+	4.39	4.01	5.81	4.30	6.66	4.49	3.71	4.91	4.34	0.27	2.33	
H ₂ O-	0.78	1.49	1.44	0.57	1.20	1.45	2.10	1.44	1.26	0.61	0.59	
TiO ₂	1.97	1.04	0.73	0.85	0.90	1.53	0.71	0.77	0.63	0.25	0.45	
CO ₂	2.59	3.69	3.32	10.71	2.15	0.95	7.13	1.05	6.48	29.12	21.21	
SO ₂	4.08	2.93	2.08	4.60	2.36	5.12	4.91	1.69	3.45	2.76	3.38	
	99.96	99.99	100.85	98.96	100.50	100.51	100.30	100.47	100.38	100.25	99.84	
<i>X-ray diffraction analyses—</i>												
Quartz	H	H/M	M	M	M	M	M	H/M	M	H/M	H/M	
Mica	M/L	M	L	L	L	M/L	M	M/L	L	M/L	L	
Kaolin	L	M	M	H/M	M	L	M	M	M/L	M	M/L	
Calcite	L	L	L	H	—	—	L	—	M	H	H	
Ankerite or dolomite	V.L	—	—	—	I.	—	H	L	—	—	—	
Hematite	L	—	—	—	—	M	H	—	—	—	V.L	

H = high, M = medium, L = low, V.L. = very low.

of material, which is characterised physically by a very small grain-size and chemically by a lower potash and higher silica and water content than mica muscovite. It is possible that a few of the dust ashes contain also traces of chlorite, but as the presence of this mineral could not definitely be established, it is omitted from the data in Table LI.

Most of the dust ashes contain carbonates besides these siliceous minerals. It is possible, on powder diagrams, to distinguish between calcite (CaCO_3) and dolomite ((Ca, Mg) CO_3), but not between dolomite and ankerite ((Fe, Mg, Ca) CO_3). Calcite and dolomite-ankerite are therefore listed separately in Table LI. Some of the dust ashes contain also small amounts of hematite (Fe_2O_3); this may have been originally present in the dusts, or, alternatively, have been formed from pyrite or iron hydroxide during ashing. All the other minerals found in the dust ashes are constituents of the original dusts.

The dust ashes were analysed chemically for the following constituents: SiO_2 , Al_2O_3 , Fe_2O_3 (including any FeO), CaO, MgO, K_2O , Na_2O , $\text{H}_2\text{O} +$ (i.e., above 105°C .), $\text{H}_2\text{O}-$ (i.e., below 105°C .), TiO_2 , CO_2 , SO_3 . In addition, CO_2 , SO_3 , and H_2S were determined on samples of the air-dried dusts. The results of these analyses are shown in the upper part of Table LI. It will be seen that SiO_2 and Al_2O_3 are the main constituents of all dust ashes, but that sometimes Fe_2O_3 , CaO and CO_2 constitute 10 per cent. or more of the ash. The means of the various ash constituents, with their standard errors, are as follows:—

Constituent.	Mean.	Standard Error of Mean.	Constituent.	Mean.	Standard Error of Mean.
SiO_2	39.2	± 7.8	MgO	2.0	± 1.2
Al_2O_3	23.6	± 6.0	K_2O	2.1	± 0.8
Fe_2O_3	7.4	± 5.4	Na_2O	0.86	± 0.42
CaO	8.3	± 8.5	TiO_2	0.78	± 0.16
CO_2	6.1	± 4.2	$\text{H}_2\text{O}+$	4.6	± 2.4
SO_3	3.5	± 1.9	$\text{H}_2\text{O}-*$	1.4	± 0.5

* The small amounts of $\text{H}_2\text{O}-$ found are due to re-absorption of water between the ashing and the analysis of the ash.

SiO_2 and Al_2O_3 are the main chemical constituents of the ashes; these are also the chief constituents of quartz, kaolin and mica. Kaolin contains in addition $\text{H}_2\text{O}+$, and mica also K_2O and possibly small amounts of Na_2O , FeO, MgO, TiO_2 , all of which are present in the ashes. There is, therefore, qualitative agreement between the results of the chemical and X-ray diffraction analyses in Table LI; the quantitative aspects will be discussed in the following section.

(b) Calculated Mineral Composition of the Dust Ashes

By combining the results of X-ray diffraction and chemical analyses it is possible to calculate the amounts of the various minerals present in the ashes and in the original dusts. The proportions of the three siliceous minerals—mica, kaolin and quartz—are calculated on two different assumptions concerning the chemical composition of the mica; the non-siliceous minerals are given as calcite and "other non-siliceous minerals". The results of these calculations are shown in Table LII.

Muscovite, kaolin, quartz. It is assumed that all SiO_2 , Al_2O_3 , K_2O shown in the ash analyses are present in these minerals, the muscovite of theoretical composition containing 45.3 per cent. SiO_2 , 38.4 per cent. Al_2O_3 , 11.8 per cent. K_2O , and the kaolin containing 46.5 per cent. SiO_2 , 39.5 per cent. Al_2O_3 .

Illite, kaolin, quartz. In this alternative calculation, the mica is assumed to be illite, instead of muscovite, the composition of the illite being 49 per

TABLE LII
Calculated mineral composition of 25 dusts

Rank of coal	Anthracite														
	High A.1		Low A.2			High A.3			Low A.5			High A.6		Medium A.8	
	2M1	2M2	1S1	2S1	2S2	2H1	2H2	3H1	1D1	1D2	1D3	2R1	2R2	2N1	
<i>Minerals as per cent. of 380°C. ash—</i>															
Muscovite	18	16	14	22	6	20	13	11	15	11	12	26	27	10	
Kaolin	30	40	59	35	35	41	67	69	49	52	58	47	44	73	
Quartz	18	12	4	15	5	13	11	5	8	5	5	11	14	1	
Illite	39	35	31	48	13	42	29	24	32	24	25	56	57	22	
Kaolin	15	27	47	17	31	25	56	60	37	43	49	25	22	64	
Quartz	14	8	1	10	4	9	8	3	5	3	3	5	8	0	
Calcite	12	11	8	7	23	11	2	5	8	N.D.	9	6	5	9	
Other non-siliceous minerals.	18	20	10*	18	29	5*	10	10	21	N.D.	16	10	11	9	
<i>Minerals as per cent. of sum of siliceous minerals—</i>															
Mica	42	36	28	48	22	41	23	20	32	28	24	49	49	19	
Kaolin	33	49	68	36	69	44	67	75	59	68	71	42	38	80	
Quartz	24	15	4	16	9	15	10	5	9	6	5	9	13	1	
<i>Minerals as per cent. of dusts—</i>															
Mica	5	3	2	6	1	6	3	2	3	2	2	8	8	1	
Kaolin	4	5	4	4	3	6	9	7	5	5	5	7	6	6	
Quartz	2.8	1.4	0.2	2.0	0.4	2.0	1.4	0.4	0.8	0.5	0.3	1.5	2.1	0.1	
Calcite	2.1	1.5	0.6	1.1	2.0	2.0	0.3	0.5	1.0	N.D.	0.8	1.1	0.9	0.7	

*Fe₂O₃+MgO

TABLE LII—(continued).
Calculated mineral composition of 25 dusts

Rank of coal	Steam coal				Bituminous coal.						
	Medium S.3	Low S.4	Low- medium S.5	Low- medium B.1	—			Low B.2	Low B.3		
					B.6						
Sample	1E1	1U1	2U1	1T1	1A1	1A2	1A3	1C1	1B1	1B2	1B3
<i>Minerals as per cent. of 330°C. ash—</i>											
Muscovite	27	24	21	19	20	24	16	31	28	8	14
Kaolin	39	33	44	30	51	21	29	42	34	14	17
Quartz	16	23	18	16	14	22	4	18	13	5	10
Illite	58	52	46	42	42	51	35	66	59	18	30
Kaolin	17	13	27	14	35	2	16	17	11	7	6
Quartz	10	18	13	11	10	17	0	11	8	3	7
Calcite	6	8	8	24	5	2	14	2	15	66	48
Other non-siliceous minerals	12	11	7	9	10	27	35	7	10	8	10
<i>Minerals as per cent. of sum of siliceous minerals—</i>											
Mica	50	47	40	46	36	52	52	53	57	48	51
Kaolin	34	28	41	33	50	15	44	32	29	37	28
Quartz	16	25	19	21	14	33	4	15	14	15	21
<i>Minerals as per cent. of dusts—</i>											
Mica	8	5	6	6	4	3	2	10	16	6	12
Kaolin	6	3	7	5	6	1	1	6	8	5	6
Quartz	2.6	2.6	3	2.9	1.7	1.9	0.1	2.9	4.2	1.9	4.7
Calcite	1.2	1	1.5	5	0.7	0.2	0.8	0.4	5.7	31	25

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cent. SiO_2 , 33 per cent. Al_2O_3 , 5.5 per cent. K_2O . This is the average composition, at 380°C ., of the "fine fractions", described in the report on the strata by Hicks and Nagelschmidt (p. 161). The fact that the fine fractions themselves contain about 10 per cent. of kaolin has been ignored in this calculation, which therefore overestimates the illite at the expense of the kaolin.

Mica, kaolin, quartz. The values in the lower six rows of Table LII are derived from the means of the results of the above two alternative calculations of the siliceous minerals (i.e., assuming the mica to be muscovite or illite).

Calcite. The maximum compatible with the ash data is calculated without regard to the X-ray diffraction data, which in some cases show calcite and, in others, dolomite-ankerite.

Other non-siliceous minerals. The sum $\text{Fe}_2\text{O}_3 + \text{MgO} + \text{CaO} + \text{SO}_3 + \text{CO}_2$ is given after subtracting the calcite.

In greater detail, the basis of the calculations given above is as follows:—

(1) A definite chemical composition, either that of muscovite or that of illite, is ascribed to the mica, although its actual composition is unknown. The most satisfactory procedure would, of course, be to isolate the mica from all dusts, or at least from a selection of them, and to analyse it. It is not known whether such isolation would be technically possible, and it would certainly involve a large amount of specialised work, which did not seem justified in the light of present knowledge.

An attempt has, however, been made to isolate the mica from the clods overlying the coal in five of the mines investigated. These "fine fractions" are believed to contain about 90 per cent. of this mica, which has been identified as illite. It seems reasonable to assume that illite accounts, at least in part, for the mica contained in the air-borne dusts, and the X-ray diffraction data, while not strictly proving this assumption, are compatible with it. It is for this reason that the illite of the composition given above has been used for one of the alternative calculations of the mica in the dust ash. The main difference of this illite from muscovite is that its K_2O content is very much lower and, since muscovite is also a possible constituent of the dusts, the illite calculation, which is based on this low K_2O may overestimate the amount of mica in the dusts. As an extreme in the opposite direction, therefore, muscovite, with its high K_2O content, has been used for the other calculation. No allowance has been made for the soda-rich mica variety—"brammallite"—found in the shale from colliery A.2.

(2) A definite chemical composition, corresponding to the formula $2 \text{SiO}_2, \text{Al}_2\text{O}_3, 2 \text{H}_2\text{O}$, is ascribed to the kaolin in the dusts, although no kaolin has been isolated from any of the dusts, nor as yet from any of the rock or coal strata.

This assumption probably does not introduce any great error, as the composition of most members of the kaolin group corresponds, except for the water content, fairly closely to the above formula. Kaolin isolated from Illinois coal by C. G. Ball (1934) had a composition corresponding to $1.9 \text{SiO}_2, \text{Al}_2\text{O}_3$.

(3) In addition to those involved in fixing the chemical composition of the siliceous minerals, the further assumption had to be made that *all* the $\text{SiO}_2, \text{Al}_2\text{O}_3$ and K_2O shown to be present on chemical analysis were in the form of mica, kaolin and quartz only. There is, as yet, no evidence that this is true, although it seems likely that at least the bulk of the three oxides in question is found in these three minerals. A very small fraction of the K_2O might, however, be present as sulphate or carbonate, and the mica estimate may, therefore, be too high. There is also the possibility that some of the Al_2O_3 is present as "free alumina". As described in the strata report, the mineral matter of the coal seam from certain mines shows, in the chemical analyses, silica : alumina ratios considerably under 2 and, in one case, as low as 1.3; while the X-ray diffraction data show the same material to contain kaolin, but no quartz nor mica. This is explained by assuming tentatively the presence of "free alumina" in small amounts. Quartz and illite raise the silica : alumina ratio in mixtures with kaolin, and all silica : alumina ratios of the dust ashes are larger than 2; there is, therefore, no direct evidence of "free alumina" in the dusts, though it cannot be denied that small amounts might be present in some of the dusts, in which case the calculated mineral composition would show less quartz than is actually present. It is further possible that some $\text{SiO}_2, \text{Al}_2\text{O}_3, \text{K}_2\text{O}$ may occur as amorphous material, as suggested by the description of the "groundmass" in the petrological report by Brammall and Leech. How much this affects the mineral composition of the dusts cannot at present be assessed.

(4) The carbonates have been calculated as calcite for all the dust ashes, although the X-ray diffraction data actually show this mineral only in the dusts from mines using limestone for stone-dusting, and in a few others, whereas the remaining dusts contain mixed carbonates, the exact composition of which is unknown. Since the amount of CO_2 is determined both on the dusts and on their ash, and since the ash content of the dusts

is known, it is possible to compare both CO_2 estimates. Such comparisons show that, for many dusts, between 20 and 60 per cent. of the CO_2 originally present is lost on ashing. It is not known whether this loss is due to simple decomposition by heat, or to reactions with sulphur compounds in the presence of coal, but it seems to show that some changes in the mineral composition of the dusts do take place on ashing at 380°C . Such changes make it difficult to decide which of the various cations were originally present as sulphide, sulphate, oxide or carbonate. No attempt has, therefore, been made to calculate pyrite, gypsum or any of the mixed carbonates, either for the dusts or for their ashes, although small amounts of all these minerals are probably present in many of the dusts. On balancing the sums of Fe_2O_3 , CaO , MgO , Na_2O against CO_2 and SO_2 from the ash analyses, a small excess of cations is usually found. The pH of suspensions of a few of the dusts varied between 7.0 and 9.2, but there did not seem to be any correlation with the rank of the coal or the incidence of pneumokoniosis.

It follows from the above comments that the calculated mineral percentages of the dusts—based as they are on several unproved assumptions—are not necessarily very accurate; but they are believed to be the best approximation to the actual dust composition that can be derived from the analytical data on present knowledge. The results, which are given in Table LII, also form a convenient basis on which the different dusts may be compared with each other. They show, as was to be expected from the chemical and the X-ray diffraction data, that the main mineral constituents of all the dusts are the same, but that there is some variation in their relative amounts.

If the data for the minerals as percentages of the 380°C . ash for any one dust (in the upper half of Table LII) are considered, it will be seen that the amounts of mica and kaolin vary considerably, according as the muscovite or the illite composition is postulated for the mica. These values probably represent extremes; their means, which are used to calculate mica, kaolin and quartz as percentages of the dust and as percentages of the sum of siliceous minerals (in the lower half of the table), are probably more representative. The corresponding two values for quartz as percentages of the 380°C . ash, on the other hand, differ less than those of mica and kaolin for any one dust, and all the quartz percentages, therefore, are probably more reliable.

When the results for the different dusts are compared, a certain amount of variation appears both between different mines and between different dusts from one and the same mine. For example, dust 2H1 contains three times as much mica and five times as much quartz as dust 3H1, from the same mine, but the amounts of kaolin are about the same in each. Analogous differences are found between dusts 2S1 and 2S2, from another mine, whereas dusts 2R1 and 2R2, from a third mine, are very similar in their mineral content.

The practice of limestone-dusting is represented in the dusts 1U1, 2U1, 1T1, 1B1, 1B2, 1B3. The percentage of calcite in the dust varies for these six samples, from 1 to 31, and in the ash it varies from 8 to 66, thus indicating considerable variations in the amounts of limestone present per unit of dust.

The variations in dust composition shown in Tables LI and LII will be discussed later (pp. 116, 119) in their relation to the rank of the coal and to the incidence of pulmonary X-ray abnormalities at the different collieries, but, before this is done, some more details must be given about the amount and size of the quartz particles in the dusts.

(c) Amount and Particle-size Distribution of Quartz in the Dusts

The X-ray diffraction data in Table LI show quartz to be present in all except one of the dust ashes, and the data in Table LII show the amounts of quartz in the various dust ashes. As already stated, the calculated quartz percentages do not differ much, whether illite or muscovite be accepted for the composition of mica in these calculations. As it is obviously important to know the amount of quartz in the dusts or their ashes as accurately as possible, a further direct determination of the quartz in the dust ashes was attempted. A semi-micro variant of the method of "rational analysis", requiring 150 mg.

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of material, was applied to 10 of the dust ashes, and their quartz contents were assessed. The results, together with the calculated quartz percentages, are shown in Table LIII. It will be seen that, with one exception, the values directly determined lie between the two figures given by the alternative methods of mineral calculation, and are, on the whole, nearer to those based on muscovite. This result confirms the value of the semi-micro method when applied to the ash from the air-borne dusts and similar material, and also the reliability of the mineral calculations, at least in regard to the quartz content.

Apart from knowing accurately the amount of quartz in the dusts, it is also important to know its particle-size distribution. Quartz was therefore isolated from 17 samples of dust derived from 12 of the mines, using the method which forms the basis of the semi-micro variant of the "rational analysis"; the particle-size distribution of the resulting material was determined microscopically. About 750 particles of each sample were measured, and the resulting size distributions are given in Table LIV. It can be seen that nearly all the quartz particles were below 2 microns in diameter. The measured values are minima, as the particles may have been slightly reduced in size during their isolation, but the agreement between the two methods (mineral calculation and rational analysis) seems to show that such reduction can only have been small. The data of Table LIV also reveal a relation between the size of the quartz and the rank of the coal; this is further discussed on p. 116.

TABLE LIII

Percentage of quartz in 10 dust ashes, calculated from silicate analysis with kaolin and muscovite, kaolin and illite, and determined by rational analysis

Colliery.	Sample.	Quartz per cent. of ash.		
		Calculated with		Determined by rational analysis.
		Muscovite.	Illite.	
A.1	2M1	18	14	17
A.2	2S1	15	10	14
A.3	2H1	13	9	13
A.3	2H2	11	8	13
A.6	2R1	11	5	8
S.4	1U1	23	18	23
B.1	1A1	14	10	12
B.2	1C1	18	11	18
B.3	1B1	13	8	12
B.3	1B2	5	3	5

PART III.—DISCUSSION

THE CONTRIBUTION OF THE ROCK STRATA AND OF THE COALSEAM TO THE MINERAL MATTER OF THE DUSTS

Although the data presented in Tables LI and LII show a broad similarity in the composition of the dust ashes, there are some variations in the relative amounts of the main constituents between different mines and between different dusts from one and the same mine. Part of these variations can be ascribed to differences in the relative contributions of the mineral matter of the coalseam and of the various rock strata—i.e., the roofs and floors, and the clods overlying the seams or occurring as dirt bands (or rashes) within the seams.

It is shown in a subsequent report (p. 157) that the overlying rock strata contain mainly mica (illite) and quartz, besides small amounts of kaolin* and

* According to the petrological report by Dr. Brammall and Mr. Leech (p. 130), the clod in the mines B.2 and B.3 contains dickite—a mineral of the kaolin group.

TABLE LIV
Particle size distributions of quartz isolated from 16 dusts

Rank of coal.	Colliery.	Sample.	Number of quartz particles of various sizes (microns) as percentage of total number of quartz particles measured.								
			Under 0.2.	0.2- 0.4.	0.4- 0.8.	0.8- 1.2.	1.2- 1.6.	1.6- 2.0.	2.0- 3.0.	Over 3.0.	
Anthracite	A.1	2M1	13.3	19.8	26.9	16.5	8.5	6.4	5.6	3.0	
Anthracite	A.1	2M2	14.7	16.9	26.6	15.6	11.9	5.7	6.0	2.6	
Anthracite	A.2	2S1	5.7	14.2	26.4	21.7	12.4	8.9	7.3	3.4	
Anthracite	A.2	2S2	9.9	17.2	27.0	19.9	11.1	6.7	5.6	2.6	
Anthracite	A.3	3H1	10.4	18.1	30.3	16.8	10.1	6.5	5.3	2.5	
Anthracite	A.3	2H2	14.0	19.9	25.2	14.8	11.2	6.4	6.1	2.4	
Anthracite	A.5	1D2	6.7	14.5	28.6	21.5	14.5	7.9	3.8	2.5	
Anthracite	A.6	2R1	15.4	18.6	30.5	14.1	8.8	4.6	5.3	2.7	
Anthracite	A.6	2R2	11.2	15.9	28.4	17.1	12.4	6.0	6.5	2.5	
Anthracite	A.8	2N1	19.2	20.1	24.9	14.5	8.3	5.6	5.4	2.0	
Steam coal	S.4	2U1	14.1	23.4	26.1	15.7	10.6	5.2	3.3	1.6	
Steam coal	S.5	1T1	12.7	21.7	25.5	15.7	11.1	6.5	4.6	2.2	
Bituminous coal	B.1	1A1	19.0	21.9	31.4	14.5	7.5	2.0	2.8	0.9	
Bituminous coal	B.2	1C1	19.9	28.0	29.3	12.6	5.5	2.3	2.0	0.4	
Bituminous coal	B.3	1B1	22.2	28.2	30.6	13.0	4.5	1.4	0.1	0.0	
Bituminous coal	B.3	1B2	21.5	27.5	31.2	10.4	5.1	1.9	1.7	0.7	

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carbonates. The mineral matter of the coalseam is more variable in character ; it contains, apart from considerable amounts of carbonates, one or several minerals of the kaolin group as main constituents ; in some of the mines it also contains quartz and mica, or possibly free alumina. As a first approximation, however, it can be said that quartz and mica in the dusts come chiefly from the rock (or from shale-dusting, in certain non-anthracite mines), whereas kaolin and carbonates are derived chiefly from the mineral matter of the coalseam.

The more rock material a dust contains, the higher will be its ash content, and, since the rock consists mainly of quartz and mica, the proportions of these two minerals in the ash should increase. This relation is, in fact, found in the present data, and is shown for quartz in Fig. 13. The percentage of

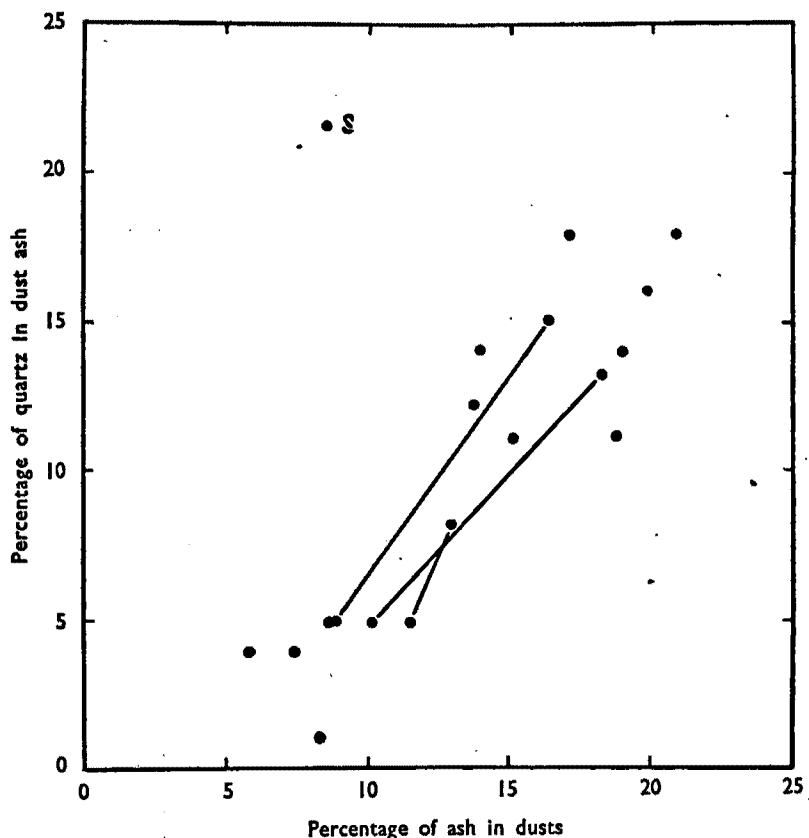


FIG. 13.—Increase of quartz percentage of dust ash with increasing ash percentage of dusts. The lines combine dusts from the same district and mine. S represents a dust from a mine with a sandstone roof.

quartz in the ash prepared at 380°C. (from the muscovite calculation) is plotted against the percentage of ash in the total dust, for all dusts except those derived from mines using limestone for stone-dusting. (This limestone obviously would increase the ash percentage without contributing any quartz.) Dusts from the same district in any mine are joined by lines. It will be seen that, despite some scattering of the points, the increase in quartz percentage of the ash with increasing ash percentage of the dusts is well demonstrated. One dust, marked S in Fig. 13, apparently has far too much quartz for its ash percentage. This dust was collected in a heading of the bituminous mine, B.6,

where a high incidence of certified silicosis occurs ; the roof in this mine consists of sandstone, and the quartz content of the dust ash is, presumably for that reason, abnormally high.

It would seem from Fig. 13 that a reduction in the ash content of a dust would be accompanied by a fall in the percentage of quartz in the ash. The coalseam material itself has a certain limited ash content, but any higher ash percentage will depend on the amount of rock contributed to a given dust. Ripping and blasting of the roof are operations which produce much of this rock dust. If quartz or mica are factors in the hazard of the collier, avoidance of the dust from these operations, e.g., by their relegation to an off-shift, might be expected to reduce this hazard. It may be objected that rock dust is introduced without any apparent hazard in the non-anthracite mines using shale for stone-dusting, but it is not known whether this shale dust is comparable in amount, particle-size, or composition with the rock dust produced by ripping and blasting in anthracite mines. The amount of rock material in the air-borne dust does not depend only on the amount of ripping or blasting. Other factors are the number of dirt bands in the seam, and the thickness of the clod that has to be mined.

The present data can also be used in an attempt to determine whether the rock contribution to the dust has the same composition as the original rock. It might be argued that, since, in ripping and blasting, the hard quartz is more shattered than the soft mica, the rock dust produced by mining should contain a higher proportion of quartz, and a lower proportion of mica, than the original rock. On the other hand, since the single crystals of mica in the clod are smaller than the single quartz grains, it might equally be assumed that the mica proportion in mining dusts would be higher, and the quartz proportion lower, than in the original rock.

To throw light upon these two possibilities, data have been used from those mines which contain no quartz or mica in the mineral matter of the coalseam (as shown in the strata report), but in which the clod and roof are handled by the collier in the course of his work ; all the quartz and mica of the air-borne dusts from these mines should come from the rocks. By comparing the ratio of quartz to mica in the rocks (from the strata report) with the same ratios in the corresponding dusts, any change can be assessed. The mines concerned are A.2 (stalls) and B.3, and the ratios are as follows :—

Ratio of quartz : mica in (a) rocks and (b) corresponding dusts

<i>Colliery.</i>	<i>(a)</i>		<i>(b)</i>
	<i>roof.</i>	<i>clod.</i>	<i>dust.</i>
A.2	1 : 4	1 : 5	1 : 5
B.3	1 : 4	1 : 8	1 : 6*

* Mean of three samples.

Similar comparisons have tentatively been made for the other dusts, after making allowances for that part of their mica and quartz which may have come from the mineral matter of the coalseam. Too few analyses both of dusts and of strata are available to permit of any precise statement, but the general impression from the results is that the rock contribution to the air-borne dusts is similar to the clod and roof itself, and that it does not contain very much more or less quartz than the rock. Shaw and Graham (1939) found similarly that the drilling dust from South Wales shale contained only slightly less quartz than the original shale, and, as described in the petrological report (p. 145), fractions smaller than 2 microns in diameter prepared from clod samples from collieries A.2 and A.3 by air-elutriation were found to be almost identical in chemical composition with the original clods.

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VARIATION OF THE DUST COMPOSITION WITH RANK OF COAL

Part of the differences in the mineral composition of the dust ashes has been explained as due to variations in the relative contributions from the overlying rock and the mineral matter from the coal seam. This concerns chiefly the relative amounts of mica, kaolin and quartz in any given dust. Another difference in the dust ash analyses can also be traced to the rock contribution. It concerns the amount of Na_2O in the dusts; or, more strictly, the ratio of $\text{K}_2\text{O} : \text{Na}_2\text{O}$.

It is shown in a subsequent report (p. 153), that the main regular variation with rank which can be observed in the chemical composition of the clod and roof samples, is a decrease in the amount of Na_2O on passing from anthracite to bituminous coal. The "fine fractions" prepared by sedimentation in water from the clods show the same effect, and it must therefore be concluded that the sodium is not present as sulphate, chloride or carbonate, but is part of the mica (illite), which is the main constituent of the clods. Since the mica in the air-borne dusts is diluted with other minerals, it is best to consider not the absolute amounts of Na_2O but the ratio $\text{K}_2\text{O} : \text{Na}_2\text{O}$.

This ratio is shown in Table LVII for the various rock and coal strata and also for the air-borne dusts. It will be seen from the vertical columns that the ratios of the dusts are intermediate between those of the rocks and of the coal strata, thus again showing the relative contribution from each source; from the horizontal lines it appears that both the rocks and the dusts show an increase on passing from anthracite to bituminous coal. The mean $\text{K}_2\text{O} : \text{Na}_2\text{O}$ ratio for the dusts from six anthracite collieries is 1.4, while the corresponding value for seven non-anthracite dusts is 3.0.

Another regular variation of the dust ash, connected with the rank of the coal, is found in the particle-size distributions of the quartz isolated from 19 of the dust ashes. Brief reference to these size-distributions, which are shown in Table LIV, has already been made (p. 112), but their trend is perhaps more easily seen from Table LV, where only two columns of figures are given, viz., the percentages of the particles under 0.4 micron in size and of those exceeding 1.6 micron. From this table it will be seen that, as the rank of the coal changes from anthracite to bituminous, the percentage of fine particles increases and that of the larger particles decreases.

TABLE LV

Size of quartz particles isolated from 16 dusts in relation to coal rank

Rank of coal.	Colliery.	Sample.	Percentage of total quartz particles :—	
			under 0.4 micron in size.	over 1.6 micron in size.
Anthracite ..	A.1	2M1	33.1	15.0
	A.1	2M2	31.6	14.3
	A.2	2S1	19.9	19.6
	A.2	2S2	27.1	14.9
	A.3	3H1	28.5	14.3
	A.3	2H2	33.9	14.9
	A.5	1D2	21.2	14.2
	A.6	2R1	34.0	12.6
	A.6	2R2	27.1	15.0
Steam coal ..	A.8	2N1	39.3	13.0
	S.4	2U1	37.5	10.1
Bituminous coal ..	S.5	1T1	34.4	13.3
	B.1	1A1	40.9	5.7
	B.2	1C1	47.9	4.7
	B.3	1B1	50.4	1.5
	B.3	1B2	49.0	4.3

The χ^2 test has been used to examine the significance of differences between the size-distribution of the quartz particles at the various collieries. In each case the total number of particles measured for a particular colliery has been taken to indicate the size-distribution of quartz particles at that colliery; wherever two samples were examined for a single colliery the results were found not to differ significantly from each other.

The samples for collieries A.1, A.3 and A.6 did not differ significantly, so the data for these three collieries were grouped for further comparison. Similarly, the samples for A.2 and A.5 did not differ significantly and could be grouped together.

Within the series of anthracite collieries we have three groups, each differing significantly from the others, (a) A.2 and A.5, (b) A.1, A.3 and A.6, and (c) A.8. In that order, the number of fine particles increases from (a) to (c).

The two steam coal mines, S.4 and S.5, did not differ significantly, and these form a further group. The results here did not differ significantly from those obtained at A.8.

Amongst the bituminous mines, B.2 and B.3 did not differ significantly and could be grouped, while B.1 differed from them.

To summarise: In order of increasing proportion of the finer quartz particles, the significantly different groups are:—

- (i) A.2 and A.5 (high rank anthracite).
- (ii) A.1, A.3 (high rank anthracite) and A.6 (lower rank anthracite).
- (iii) A.8 (lower rank anthracite) with S.4 and S.5 (steam coal).
- (iv) B.1 (bituminous).
- (v) B.2 and B.3 (bituminous).

The petrological examination of the roofs and clods described in the report by Brammall and Leech has revealed a similar decrease in the size of the quartz grains in thin sections of the rocks, in passing from anthracite over steam coal to bituminous coal.

TABLE LVI

Size distributions of non-coal fractions of 10 dusts and of their quartz residues

Rank of coal.	Colliery.	Sample.	Non-coal fraction (N.C.) or quartz residue (Q).	Number of particles of various sizes (microns) as percentage of total number of particles of 0.4 micron or greater size:—				
				0.4–0.8.	0.8–1.2.	1.2–1.6.	1.6–2.0.	over 2.0
Anthracite	A.1	2M1	N.C.	39.4	28.2	16.5	3.0	12.9
	A.1		Q.	40.2	24.7	12.7	9.6	12.8
	A.2	2S1	N.C.	47.8	24.7	16.6	4.5	6.4
	A.2		Q.	32.9	27.1	15.4	11.1	13.5
	A.2	2S2	N.C.	45.0	29.8	14.9	5.8	4.5
	A.2		Q.	37.1	27.3	15.2	9.2	11.2
	A.3	2H2	N.C.	44.0	27.1	10.9	5.3	12.7
	A.3		Q.	38.1	22.4	16.9	9.7	12.9
	A.3	3H1	N.C.	57.7	23.4	10.5	4.6	3.8
	A.3		Q.	42.4	23.5	14.1	9.1	10.9
Steam coal	S.4	2U1	N.C.	43.4	28.3	16.3	7.4	4.6
	S.4		Q.	41.8	25.2	16.9	8.3	7.8
	S.5	1T1	N.C.	51.8	27.0	11.2	5.0	5.0
	S.5		Q.	38.9	24.0	16.9	10.0	10.2
	B.2	1C1	N.C.	45.8	27.3	12.7	8.1	6.1
Bituminous coal.	B.2		Q.	56.3	24.2	10.6	4.3	4.6
	B.3	1B1	N.C.	31.9	25.8	22.1	12.2	8.0
	B.3		* (HCl) N.C.	52.9	24.0	11.7	4.6	6.8
	B.3		Q.	61.6	26.2	9.1	2.8	0.3
	B.3	1B2	N.C.	23.4	25.0	26.4	12.0	13.2
	B.3		Q.	61.1	20.4	9.9	3.6	5.0

* HCl—extracted non-coal fraction.

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In some of the mines mentioned above, the non-coal fraction of the whole dust was also examined for size-distribution. Table LVI shows the size-distribution of non-coal fractions and corresponding quartz residues, pair by pair. (In respect of one of the samples from colliery B.2, an additional size-distribution is given for a preparation in which the non-coal fraction of the air-borne dust had been acid-treated in order to remove the limestone due to stone dusting.) While the size-distributions of the non-coal fractions of the whole dusts, given in Table L, show no clear difference as between the anthracite and the non-anthracite mines, it will be seen from Table LVI that such differences do occur when the size-distributions of the particles in the quartz residues are compared.

No other regular variation in the composition of the dust ash seems to occur with decreasing rank of coal, apart from the increase in the K_2O/Na_2O ratio and the decrease in the particle size of the quartz. This may be seen from the data in Table LVIII, where mean values for the ash percentage of the dusts, and for the composition of this ash, are shown for the four groups, high-rank anthracite, lower-rank anthracite, steam coal and bituminous coal, each group being represented by three mines. In calculating these mean values, the data of Tables LI and LII were used to give mean values for the different mines, where several dusts per mine had been analysed, and the means of the three mines in each group were then taken. Such variation as can be found in the data is probably due to the stone dusting. Thus, the ash percentage for the two anthracite groups is very similar, 13.6 and 12.7; it is higher for steam coal (18.8), and still higher for bituminous coal (26.8). This might mean merely that, at least as regards the mines examined, relatively more stone dust is used in the bituminous than in the steam coalmines. The fact that quartz and siliceous minerals, expressed as percentages of the dusts, are higher in non-anthracite than in anthracite mines, probably reflects the effect of shale-dusting. The same effect is seen in the composition of the sum of siliceous minerals: the non-anthracite dusts contain more mica and quartz and less kaolin than the anthracite dusts. An alternative explanation would be that the non-anthracite seams contain more dirt bands or that more clod has to be mined in non-anthracite than in anthracite mines.

It is thus seen that the variation in dust composition related to changing rank of coal is partly due to the effects of stone dusting, and partly to the changing character of the overlying rock, e.g., increase in K_2O/Na_2O ratio, and decrease in size of quartz. To what extent the variation in composition of the "groundmass", described in the petrological report by Brammall and Leech, is reflected in the dust composition, cannot be assessed from the present data.

TABLE LVII

The molecular ratio K_2O/Na_2O of rock and coalseam strata and of the dusts

Rank of coal	Anthracite.						
	Colliery	A.1.	A.2.	A.3.	A.5.	A.6.	A.8.
Fine fraction		2.8	4.0	3.2*	—	—	—
Clod		2.3	3.2	3.5*	3.9*	3.0	—
Roof		1.3	2.9	2.7	3.3*	2.0	—
Dust		1.0*	1.3*	1.3*	0.95*	2.9*	0.85
Extraneous ash		0.79	0.42	1.2	0.81	—	—
Whole seam ash		0.30	0.25	0.33*	—	—	—
Inherent ash		0.12	0.09	0.24	—	—	—

* Mean of several samples.

TABLE LVII—(continued).

The molecular ratio K_2O/Na_2O of rock and coalseam strata and of the dusts

Rank of coal ..	Colliery ..	Steam coal.			Bituminous coal.			
		S.3.	S.4.	S.5.	B.1.	B.6.	B.2.	B.3.
Fine fraction ..	—	5.7†	—	—	—	—	—	6.9
Clod	—	10.5	—	—	—	—	5.3	6.5
Roof	—	4.7	—	—	—	—	5.9	5.6
Dust	3.7	2.3*	3.2	2.9	2.6*	2.9	2.9*	2.9*
Extraneous ash ..	—	1.1	—	—	1.3	2.3	1.2	1.6
Whole seam ash ..	—	0.48	—	—	—	—	—	—
Inherent ash ..	—	0.26	—	—	—	—	—	0.14

* Mean of several samples.

† Isolated from roof material.

TABLE LVIII

Mean values of dust and ash composition grouped according to rank of coal

Rank of coal	Anthracite.		Steam coal.	Bituminous coal.
	High.	Lower.		
No. of mines	3	3	3	3
No. of dusts	8	6	4	5
<i>Per cent. of dust—</i>				
380°C. ash	13.6	12.7	18.8	26.8
Quartz	1.4	0.8	2.8	2.7
Siliceous minerals (including quartz).	10.1	10.4	14.6	17.3
<i>Per cent. of 380°C. ash—</i>				
Mica	24	26	36	35
Kaolin	39	50	26	29
Quartz	9	6	15	11
Non-siliceous minerals ..	26	20	23	25
<i>Per cent. of sum of siliceous minerals—</i>				
Mica	33	32	47	47
Kaolin	54	62	34	38
Quartz	13	6	20	15
Molecular ratio K_2O/Na_2O ..	1.2	1.6	3.1	3.0

All the variations in dust composition so far considered concern the non-coal fraction, but it must not be forgotten that the main part of the air-borne dusts is coal. This coal has been found, in the few samples examined, to be representative of the whole seam material; it must, therefore, be expected to reflect any change in rank. Unfortunately, however, no differences in the chemical and physical properties of the ash-free coal substance, related to the coal rank, have so far been demonstrated which might be relevant to the action upon the lungs, of dusts containing the different types of coal.

CORRELATION OF DATA WITH INCIDENCE OF PNEUMOKONIOSIS

In the preceding part of this discussion certain variations in the ash content of the air-borne dusts and in the chemical and mineral composition of the ash, have been noted. These variations have been related to two factors, (i) the

TABLE LIX

Mean values of dust and ash composition grouped according to incidence of pneumokoniosis

Incidence of pneumokoniosis.	All collieries.				Anthracite collieries only.*			Non-anthracite collieries only.		
	High.	Medium and low-medium	Low.	All mines.	High.	Low.	All mines.	Medium and low-medium	Low.	All mines.
No. of mines	3	4	5	12	3	2	5	3	3	6
No. of dusts	7	4	12	23	7	6	13	3	6	9
<i>Per cent. of dust—</i>										
380°C. ash	16.2	15.7	20.9	18.0	16.2	11.0	14.1	18.1	27.5	22.8
Quartz	1.7	1.8	2.2	1.9	1.7	0.8	1.3	2.4	3.1	2.8
Siliceous minerals (including quartz).	13.1	12.3	13.8	13.1	13.1	7.7	10.9	14.1	17.8	16.0
<i>Per cent. of 380°C. ash—</i>										
Mica	31	30	31	30	31	21	27	34	37	36
Kaolin	39	40	32	36	39	43	40	31	25	28
Quartz	10	10	10	10	10	6	8	13	13	13
Non-siliceous minerals ..	20	21	27	24	20	30	24	22	26	24
<i>Per cent. of sum of siliceous minerals—</i>										
Mica	39	38	42	40	39	30	35	44	50	47
Kaolin	48	49	44	47	48	62	53	39	32	36
Quartz	14	13	14	14	14	8	12	17	18	17
Molecular ratio K_2O/Na_2O	1.7	2.7	2.1	2.2	1.7	1.1	1.5	3.3	2.8	3

* One medium-incidence mine dust is omitted.

relative proportion of rock and coalseam material and (ii) the transition from anthracite through steam coal to bituminous coal. The data will now be re-grouped to see whether there is any relationship between dust composition and the incidence of pulmonary X-ray abnormalities amongst colliers in the various mines. (As two of the dusts, 1A2 and 1A3, were collected from a mine not covered by the medical survey, they will be omitted from this discussion.)

The medical survey has shown a double contrast. In the South Wales coalfield as a whole, the incidence of pulmonary X-ray abnormalities in the colliers decreases gradually in passing from anthracite to bituminous coal; in the anthracite area itself, high, medium and low incidence mines exist.

A complication in analysing the data is provided by the fact that stone-dusting is practised only in the non-anthracite mines, none of which has a high incidence of pneumokoniosis; the stone dust at the time of sampling was either shale or limestone. Shale is composed mainly of mica and quartz: hence it is not possible, in analysing the dust ash, to distinguish between such shale and material from the overlying rock. The effect of limestone-dusting is to increase the total ash of the air-borne dusts without increasing the content of siliceous minerals; but, again, the effect cannot be clearly separated, as carbonates (sometimes calcite, sometimes ankerite-dolomite) occur, in amounts up to 20 per cent. of the ash, in the air-borne dusts from the anthracite mines. If the percentages of quartz, mica and kaolin in the sum of the siliceous minerals are considered, the effect of the limestone, but not that of the shale dust, will be eliminated.

In arranging the data, the four incidence groups, in respect of pneumokoniosis—"high", "medium", "low-medium" and "low"—were reduced to three, by classing together medium and low-medium incidence mines. Mean values were calculated for the percentages of total ash, quartz and sum of siliceous minerals in the dusts; of mica, kaolin, quartz and non-siliceous minerals in the 380°C. ash; of mica, kaolin and quartz in the sum of siliceous minerals; and for the molecular ratio $K_2O : Na_2O$. There are two ways of obtaining mean values, either by taking all 23 dusts as units and in this way weighting the data for the mines of which several dusts were analysed, or by first taking the mean values for the different mines, and then taking the means for the different incidence groups. The results with both methods of calculation are so similar that we give only those for the latter method, which compares the data for 12 mines—3 with high, 4 with medium or low-medium, and 5 with low incidence of pneumokoniosis.

The results are given in Table LIX. They show an almost surprising homogeneity. High and medium incidence groups give nearly the same values throughout, and the fact that the low incidence group has a higher ash percentage, higher percentage of non-siliceous minerals and lower percentage of kaolin in the ash seems to be due to the stone-dusting, limestone causing the two first and shale the first and third effects. The $K_2O : Na_2O$ ratio is highest for the medium incidence group, probably because this contains the lowest proportion of anthracite dusts (see p. 116). From a comparison of the dusts from all mines investigated it seems, therefore, that there is no correlation between the ash percentage or the composition of the dust ash and the incidence of pulmonary X-ray abnormalities among the workers.

A different impression is gained, however, if the anthracite dusts only are compared. For such a comparison we have seven dusts from three mines with a high incidence of pneumokoniosis, one from a mine with a medium incidence, and six from two low-incidence mines. Omitting the medium incidence dust, the data for dusts derived from high and low incidence anthracite mines are compared again, by first taking the mean values for the mines and then the means for the two groups. It will be seen (Table LIX) that the dusts from the low incidence anthracite mines have less ash, quartz and siliceous minerals,

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and that their ash has a higher percentage of non-siliceous minerals, than the dusts from the high incidence mines. The differences in ash and quartz percentages of the dusts are statistically significant (*t* test).

A final comparison may be made of the amount and particle size of quartz in the dusts from different mines; the latter are here limited to high and low incidence anthracite, and low incidence non-anthracite. (As high incidence non-anthracite mines are quite exceptional in South Wales, no such mine was included in the medical survey.) The results do not seem to show any relevant contrasts when all the groups are considered:—

Mean quartz—and quartz size-distribution—percentages in relation to rank of coal and incidence of pneumokoniosis

Rank of coal.	Anthracite.		Non-anthracite.	All.
	High.	Low.	Low.	Low.
Incidence of pneumokoniosis.				
Quartz per cent. (by weight) of dust (from Table LIX).	1·7	0·8	3·1	2·2
Per cent. of total quartz* which is—				
under 0·4 micron	31·0	23·0	45·0	36·0
over 1·6 micron	15·0	15·0	6·0	10·0

* Percentage of number of quartz particles (from Table LV).

Apart from those from the seven high and six low incidence anthracite mines there is one sample from a medium incidence mine, A.8. This dust is specially remarkable, as it contains only about 0·1 per cent. of quartz. The overlying rock is not handled by the collier in this mine, and the mineral matter of the coal seam does not contain more than traces of quartz (p. 178). Further work on dusts in this mine seems called for, as it may be possible to establish the existence of a hazard in the absence of quartz. This hazard might be due to the other siliceous minerals in the dust. Quartz, in all 23 dusts, accounts for 12 to 37 per cent. of the total SiO_2 found, the mean value being 25 per cent. The remainder of the SiO_2 is accounted for by mica and kaolin, but the dusts may contain some amorphous silica, as pointed out in the petrological report by Brammall and Leech. There is also the further possibility that anthracite coal dust itself constitutes a greater hazard than non-anthracite coal dust, either alone or in conjunction with the siliceous minerals found in the air-borne dusts.

Summarising these findings, it may be said that, within the anthracite area, dusts from mines with a high incidence of pneumokoniosis contain slightly more ash and siliceous minerals, and about twice as much quartz, as dusts from mines with a low incidence. If, however, the dusts from all mines are compared, this contrast no longer exists; dusts from high, medium and low incidence mines show no differences in their ash composition and in the ash percentages, other than those which are apparently due to stone dusting; nor is there much contrast in the size distribution of quartz in the dusts.

In judging the significance of these conclusions, it must be borne in mind that only 25 dusts were examined, but it seems doubtful whether any different conclusions would have been reached had the number of analyses been larger.

SUMMARY AND CONCLUSIONS

1. The composition of the air-borne dusts in certain coalmines in South Wales has been studied, in order to correlate the results with the findings of the medical survey in the South Wales coalfield.

2. Twenty-five dust samples from 13 mines were collected during the working shifts for several days, at a distance of a few feet from the coalface; the samples are believed to be representative of the dust to which the collier is exposed.

3. The grain size distribution of 14 dusts was determined microscopically, separate counts being made for coal and non-coal particles; 1 to 3 per cent. of all particles exceeded 5 microns in diameter, but only up to 0.2 per cent. of all particles were non-coal particles larger than 5 microns. Thus, the bulk of the samples, and nearly all the non-coal material, is of respirable size.

4. Chemical and coal-petrographical analyses of a few samples show the coal in the dusts to be very similar to the coal in the seams and not to contain a higher concentration of fusain.

5. All dusts were ashed at 380°C. and their mineral content determined as far as is possible by combined X-ray diffraction and chemical analysis; all were found to contain members of the kaolin and mica groups, and, with one exception, quartz. Apart from these siliceous minerals, the dusts contained carbonates, e.g., calcite or ankerite-dolomite, while some of them also had small amounts of sulphates, sulphides and possibly oxides or hydroxides.

6. The percentage of quartz in the dust ash varied from 1 to 20. Direct quartz determinations (by rational analysis) showed good agreement with the calculated quartz percentages obtained from the combined chemical and X-ray diffraction analyses. The percentage of quartz in the dusts varied from 0.1 to 4.7 (mean value 1.9 per cent.), while the total SiO_2 varied from 2 to 16 per cent. (mean value 6.6), the remaining SiO_2 being accounted for by kaolin and mica.

7. From the results of the investigation of the strata (p. 185) it may be concluded that the kaolin and carbonates in the dusts come mainly from the mineral matter of the coal seam, and the mica (illite) and quartz mainly from the associated rocks (roofs, clods, rashes, dirt bands, floors). In certain mines the mineral matter of the coal seam may have supplied some mica and quartz. In the absence of limestone dusting, the percentage of quartz in the ash tends to increase with increasing ash percentage of the dusts (Fig. 13). If, therefore, quartz (or mica) is held to be harmful, rock dust, produced, for example, by blasting and ripping, should be eliminated as far as possible from the air breathed by the workers.

8. In the two following reports in this symposium a decrease in the sodium content of the mica (illite), which is the main constituent of the rocks, and a decrease in the particle-size of the quartz, are shown to occur in passing from anthracite over steam coal to bituminous coal. Small parallel changes—expressed as an increase in the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio and as a change in the relative frequencies of quartz particles over 1.6 and under 0.4 micron—are also seen in the composition of the dust ash.

9. No relation is found between the incidence of pulmonary abnormalities amongst colliers and the ash percentage, or ash composition, if all the dusts are compared. Anthracite dusts alone as a group show a slight quantitative relationship; those from high incidence mines have more ash and siliceous minerals, and about twice as much quartz, as the dusts from low incidence anthracite mines. The dust from a medium incidence anthracite mine does not contain more than 0.1 per cent. of quartz. If confirmed by further work, this finding might prove important, in showing that either some other mineral constituent or the anthracite coal itself, or more probably their combined occurrence, may constitute a hazard.

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CHRONIC PULMONARY DISEASE IN SOUTH WALES COAL-MINERS—II. ENVIRONMENTAL STUDIES

E.—THE PETROLOGY OF COAL-MEASURES, SHALES AND SANDSTONES

from six selected collieries in the South Wales Coalfield

BY

A. BRAMMALL, D.Sc., Ph.D., F.I.C.,

AND

JOHN G. C. LEECH, A.R.S.M., D.I.C.

(Department of Geology, Imperial College of Science and Technology, London.)

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I.—GENERAL

INTRODUCTION

In the investigation of chronic pulmonary disease amongst South Wales coalminers, measurements of the concentration of dust in the mine air, and qualitative examinations of the air-borne dust, were clearly necessary; and a further line of inquiry indicated was a petrological study of the strata from which the dust dispersed during mining operations was derived. We were invited to determine whether the strata exposed at the coal-face in mines with a low incidence of pneumokoniosis differed petrologically from those exposed in mines with a high incidence.

Samples of material representative of strata exposed at six collieries, three anthracite (A.1, A.2, and A.3) and three non-anthracite (S.4, B.2, and B.3), were supplied to us. Those from colliery A.3 were provided by Major R. Yates, then H.M. Senior Inspector of Mines for the Swansea Division, and those from the remaining collieries were supplied by Mr. D. Hicks, Officer-in-Charge of the Coal Survey Laboratory, Cardiff.

The first batch of samples to be examined came from colliery A.3. The samples included a clod—a type of shale (p. 127)—which differs significantly from its analogues in certain South Lancashire collieries with which we were already familiar. The A.3 clod is more compact and indurated, and more fissile, than the South Lancashire types, and it shows microstructures compatible with an early stage of metamorphism. These metamorphic features, which include the presence of secondary quartz, were of considerable interest, but their possible relevance to the pneumokoniosis inquiry could not be assessed until samples from other mines had been examined.

The next batch of samples examined was that from colliery A.2. These were composed mainly of another type of shale, which differs, again significantly and in the same sense, from the colliery A.3 and the South Lancashire shales alike. The A.2 facies shows foliation due to pressure; it is traversed by numerous polished and slicken-sided shear-planes which are filmed or encrusted with a white micaceous mineral* (Plate EI); and it has undergone a considerable amount of plastic deformation, with disruption. Such dynamic effects are usually associated with destructive mineral change of a retrograde kind.

Of the samples from the remaining collieries, those from colliery A.1 included a shale closely comparable with that from colliery A.3. The shales from the three non-anthracite collieries did not, at first sight, appear to differ much from their South Lancashire analogues.

This introductory reference to shales in particular is justified by the fact that shale substance is very sensitive to the determinants of metamorphic grade, and is present in every stratigraphical unit examined, the coals included. Literature dealing with the petrology of metamorphosed shales is copious, but the shales themselves have hitherto received less attention than has been directed to the study of clays and soils.

In the sandstone, shale substance is mainly interstitial to the quartz grains and acts as a cohesive agent. But there is every gradation between sandstones that are rich in quartz and shales in which quartz is relatively scarce. The following gives the percentages of "free silica" (presumed to be quartz) determined by A. Shaw on selected clod samples:—

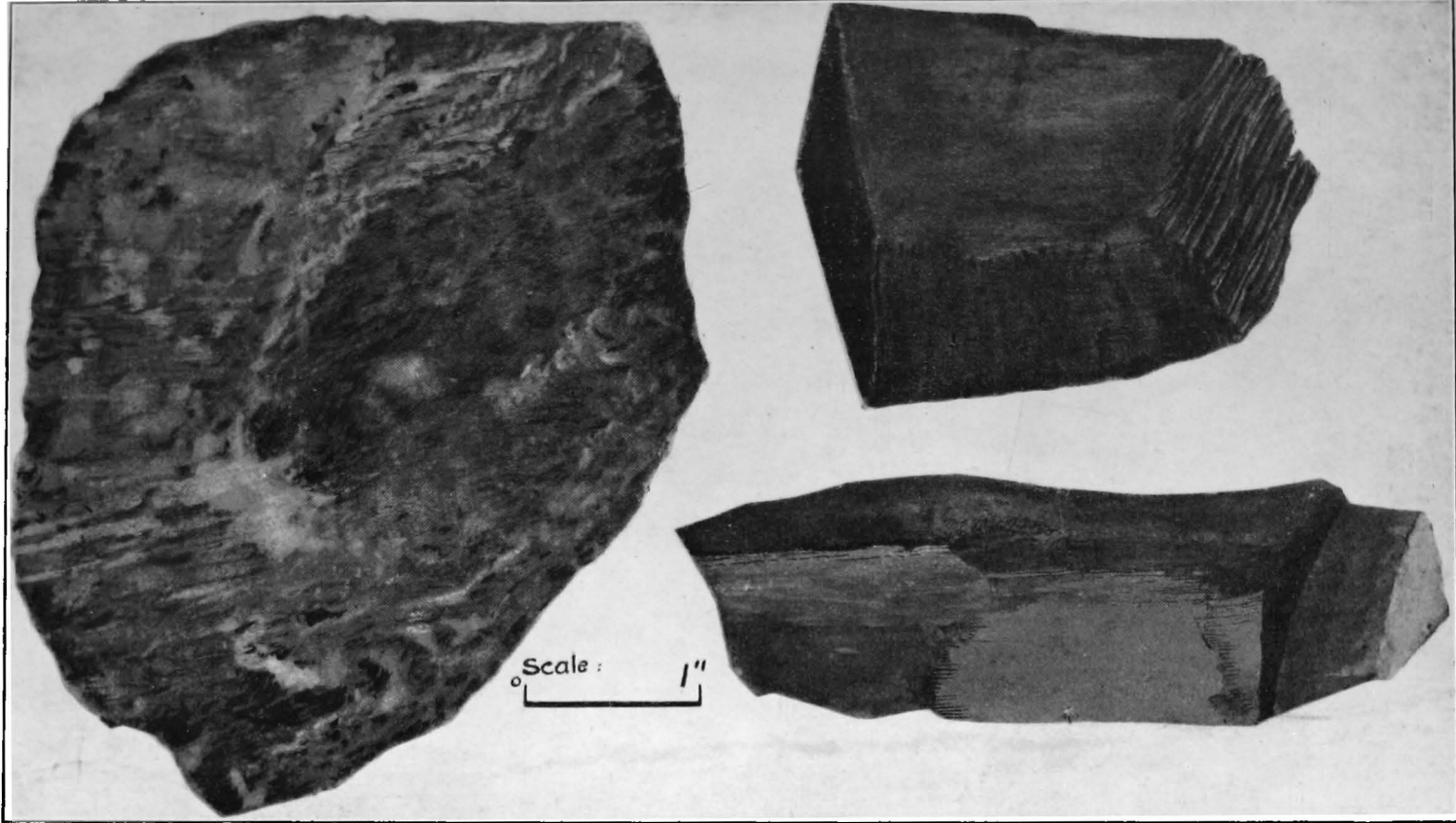
<i>Clod from Colliery</i>	<i>Percentage of free silica</i>
S.4	8
B.3	11
A.3	14.6
A.2	17
B.2	18
B.2	22

With gradation towards the hard sandstones and grits, the so-called "silica rocks", the amount of free silica rises—to 80 per cent. or more.

The content of free silica is not the sole determinant of hardness. Pyrite and the carbonate ankerite also impart hardness to shale; but this quality

* X-ray determinations, by Mr. F. A. Bannister, M.A., Assistant Keeper, Natural History Museum, South Kensington, prove this substance to be soda-illite—a new mineral species, to which Mr. Bannister has given the name "brammallite." (*Agenda: Mineralogical Society*, 4th June, 1942.)

(27700)



Shale from Colliery A.2. Typical appearance of sheared fragments—showing micaceous veneer on joint- and shear-planes.

s determined to a large extent by the geological history of the shale, which originated as clayey sediment. An appreciation of this fact is essential to any interpretation of the data presented in the following sections.

THE CLAY-SHALE-SLATE SEQUENCE

Clays

Clays in general represent the finely divided residual products of the weathering process acting on rocks in mass. By "weathering" is meant the destructive alteration of rock-forming minerals by oxidation, hydration, and the leaching out of the more soluble bases—typically as carbonates. Mineral dusts gaining access to the respiratory tract are exposed to similar dissolution processes, but in a more complex environment. The mineralogy of clay sediment may be broadly classified thus:—

I. *Penultimate residuals.*

These retain small percentages of the more readily leached bases, e.g. lime, soda, potash, magnesia and ferrous oxide.

- (a) Micas of the sericite-illite kindred.*
- (b) Members of the beidellite kindred, characterized by high base-exchange capacity.
- (c) Ill-defined, obscurely crystalline (in some cases probably amorphous) substances, similar in general composition to well-defined crystalline species in other groups; probably colloids:*

 - (i) Chloritic matter.*
 - (ii) Serpentinic matter.‡
 - (iii) Glauconitic matter.‡
 - (iv) Kaolinitic matter.‡
 - (v) Beidellitic matter, etc.‡

II. *Ultimate residuals.*

Theoretically, these are free from the more readily leached bases:

- (a) Kaolinite and its kindred, in which alumina and silica are still in chemical combination; crystalline.*
- (b) Primitive gels:
 - (i) Free hydrated silica.‡
 - (ii) Free hydrated alumina.‡
 - (iii) Free hydrated ferric oxide* and oxides of manganese.*

These amorphous substances are liable to form mechanical mixtures ("mixed" coagulum) by mutual precipitation, and to adsorb cations and anions somewhat selectively.

Such composite bodies could be classified in the manner indicated above (I (c) (i-v)).

III. *Minerals highly resistant to weathering.*

- (a) Quartz,* and muscovite-mica.*
- (b) Minor accessory species—as minute crystals and crystal-fragments separable mechanically (though not completely) from clay-substance: Rutile* ; zircon,* sphene,* epidote,* tourmaline,* kyanite,* staurolite,* ilmenite,* etc.—in small, usually negligible, amounts.
- (c) Incompletely altered fragments of albite* or other feldspar, biotite-mica,* chlorite,* etc.

IV. *Precipitations from aqueous solutions constituting the natural "wetness" of clay-sediment.*

- (a) Carbonates—typically calcite.*‡
- (b) Sulphate—commonly gypsum;* occasionally barytes.*
- (c) Phosphate—chiefly a basic phosphate of lime.*

Aqueous extracts from clay-substance usually contain chlorides,* sulphates,* and carbonate (in traces).* and a varied assemblage of bases—notably alkalis, magnesia and lime. Silica would appear to be invariably present in these aqueous extracts.

Shales

Shales result from the compaction, by dead-weight pressure, of clay-sediment composed of varying proportions of the substances listed above. Compaction tends to reduce the quantity of indeterminate mineral matter,

* Present in the South Wales shales.

‡ Presence in the shales is regarded as a possibility.

† Occasionally conspicuous in "sandy" bands, e.g. the Stanlyd "strong clift".

by progressively aggrading it to more definitely crystalline and specific minerals. The mechanism of this reconstitution-and-recrystallisation process is highly relevant to the present inquiry, and it may be said to involve a reversal of the effects of "weathering".

Whereas weathering is characterized by the breakdown of crystal structure, to the accompaniment of hydration, oxidation, a variable degree of de-silication, and the leaching of the more mobile bases—typically as carbonates—metamorphism due to compaction is characterized by dehydration, de-oxidation (e.g. the reduction of ferric to ferrous oxide), and de-carbonatization, accompanied by re-silication and the "fixing" of mobile bases in definitely specific crystalline compounds. Clay colloids undergo progressive dehydration; adsorbed bases enter mica, chlorite, feldspar, etc.; alumina and silica adjust themselves to proportions proper to such specific minerals evolving under physical conditions which are themselves changing; ferric oxide tends to be reduced to ferrous oxide and to enter new minerals, and even carbonates may be destabilized—in favour of silicates.

Slates

Slates originate from shales under intense lateral compression, whereby shale mineralogy is aggraded and simplified to (a) a meta-stable ternary system composed of quartz, sericite-mica, and chlorite, associated with (b) subordinate amounts of minor accessory species—typically rutile, carbonate, pyrite, and epidote, with some others of more casual occurrence (Brammall, 1921). There is little, if any, amorphous residuum.

The main petrological question at issue in the present inquiry is, how far aggradation has proceeded in the various South Wales shales.

II.—SOUTH WALES SHALES

(A). MINERALOGICAL DETAIL

The fabric of the South Wales shales examined comprise (a) relatively conspicuous granules, flakes, and fibres, set in (b) a dusky greenish-brown matrix, composed of an intricate plexus of extremely minute flakes and fibres enmeshing dust-fine mineral particles and coaly matter.

These two textural elements are cemented by a transparent ultimate-groundmass substance, much of which is specifically indeterminate by microscopy alone. The whole assemblage constitutes a complex silicate-system in which growth of new, or secondary, minerals has already begun.

The ultimate groundmass is in many respects comparable with a solution which has already precipitated some solid phases and is able to precipitate more under appropriate physical conditions. So long as this essentially unindividualized, and possibly in part amorphous, groundmass substance persists, it should retain some reserve quantity of every component already incorporated in secondary growths. Moreover, meta-stability governs the chemical composition of complex evolutes such as mica, which tends to equilibrate its composition to that of the changing groundmass. Some meta-stable species may fail to do so; they may even be destabilized and thus become contributory to evolving species stable under the conditions prevailing.

The particular conditions in the present case were determined by the geological history of the region. The effects of compaction, or dead-weight pressure, are general, but they were locally modified—essentially enhanced—by lateral tectonic compression; one effect of this was to initiate fold-structures, which are especially prevalent in the north and north-west parts of the coalfield. Where plastic deformation has resulted in dislocation and shearing, compaction effects become more or less obscured, and the "milling" action induces mineral changes, some of which are retrograde in kind.

At Colliery A.2, compression was locally relieved by thrust-dislocation and shearing. It was accompanied by migration of solutions carrying silica, alumina, and alkalis (notably soda), which were precipitated as "mica-rich aggregate" on joint- and shear-planes (Plate EI).

Tectonic compression did not operate with equal effect over the whole region. It attained a maximum in an area within which lie collieries A.1, A.2 and A.3.

If petrological features directly related to compression were arranged on a progressive scale, that scale would have its zero point in the clay grade, and would rise through the shale to the slate and higher grades. None of the samples examined attains to the slate grade.

The S.4, B.2 and B.3 shales fall within the lower part of the shale range, and the A.1 and A.3 shales claim a place in its higher part, as do also the A.2 shale samples, with the qualification discussed below.

Colliery A.2 clod. The original bedding, clearly preserved in other facies, is often completely obliterated by plastic deformation—accompanied by the production of an intricate system of listric slip- and shear-surfaces, between which close foliation simulating that in low-grade schists occurs. Some of the slabs received might fairly be described as “fault gouge” (Plate E I).

Joint- and shear-planes are filmed or encrusted with a white deposit (usually sheared), composed mainly of mica contaminated with kaolinite and probably also another substance still to be identified. The one aggregate sample analysed represents such a mixture; but it is dominantly sodic. The soda is probably combined mainly in a mica, which is therefore an exceptional variety.* Hydromuscovite in a comparable setting has been described by Brammall & Leech (1937). In contrast with the dominantly potassic mica prevailing in the clods, etc., this film-and-crust mica is essentially free from inclusions (cf. Plate E VI, Fig. A). The mica in the A.2 clod itself is of anomalously “fine” grade.

The groundmass constitution has been modified by both shearing and immigrant solutions. The film-and-crust micaceous deposit represents a precipitation from some such solution, which was probably of hydrothermal origin.

The A.2 clod is in contrast with the A.3 clod in respect of both (a) texture and lithology, and (b) base-exchange capacity. The basis of the first contrast has already been outlined; the second is to be gauged from the following summary of relevant data (Table LX).

TABLE LX

Material.	Aq. extract approx. pH		Base-exchange capacity	
	Whole sample.	Air-elutriated fraction.	Whole sample.	Air-elutriated fraction.
<i>A.2**</i> :				
Milled clod	8.4	8.0	33	34
Micaceous deposit	8.2	—	16	—
<i>A.3**</i> (Stanlyd. Glam.) :				
Milled clod	8.3	7.9	69	59
After one diethylamine extraction	—	—	50	—
After two extractions	—	—	32	—
Strong clift	7.9	—	23	17
Fireclay floor	7.9	7.2	27	17
Lower bord	6.8	—	5	6
Upper bord	6.4	6.8	10	6
<i>S.4-B.3</i> :	7.2	—	—	—
	to			
	8.2			
<i>Mine-dusts</i> †	7.1	—	—	—
	to			
	9.2			
<i>Cf. Robust muscovite</i> ‡	—	—	53	75

** Data determined by Geochemical Laboratories, London.

† Communicated by Dr. G. Nagelschmidt.

‡ A detailed analysis of this, with a discussion of its constitution, is given by Brammall & Leech (1937); see also Table LXI, Anal. No. 2.

A primitive form of white mica (hydromuscovite, sericite, or illite) is one of the earliest products of the reconstitution process. It is commonly accompanied by some member of either the kaolinite group, or the beidellite group, or both.

The mica is relatively easy to recognize, though recognition depends largely on the habit and the orientation (and consequently the birefringence) of flakes forming part of the heterogeneous groundmass-plexus. The recognition of associated kaolinitic or beidellitic terms is often difficult or impossible by microscopy alone, whether it be applied to the thin rock-slice or to shale “powder”.

* This is now known to be soda-illite; see footnote on p. 126.

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which usually contains a high proportion of composite particles. In general, positive identification may be practicable down to a limiting grade-size of 3μ - 5μ .

Kaolinite and its kindred₄

The composition of these is essentially constant:—

(a) Kaolinite, dickite, and nacrite: $Al_2Si_2(OH)_6$ —empirically $2H_2O \cdot Al_2O_3 \cdot 2SiO_2$.

(b) Halloysite: $Al_2Si_4(OH)_{10}$, or $4H_2O \cdot Al_2O_3 \cdot 2SiO_2$.

Here may be included more hydrous "crystalline colloids" having the Al_2O_3/SiO_2 molecular ratio proper to the group, but not yet aggraded to the degree of crystallinity attained by a more specific member with which they may be associated. In a scheme of progressive reconstitution they would rank as "lag" terms. The presence of such terms in the S.4-B.3 suite is deemed probable.

Kaolin was present in all or most of the shale samples received. An early provisional identification of kaolinite in the A.3 anthracite was confirmed by Dr. Nagelschmidt.

Dickite, a member of the kaolin group, is abundant and often conspicuous in the B.3 shale (Plate E VI, Fig. B). In the B.2 shale it is less obvious; and in the S.4 shale it is either too poorly developed for recognition, or it is lacking.

Primitive white mica: hydromuscovite, sericite or illite

Unlike the kaolinite kindred, primitive white mica is of complex and variable composition. The few recorded analyses of "sericite" differ considerably, probably owing to the difficulty of isolating a mica aggregate which is uncontaminated with matrix material and free from alien inclusions.

In respect of bulk composition, both primitive white mica and the more robust "true muscovite", common in granite rocks, are in strong contrast with "theoretically pure muscovite". The measure of this important difference is shown in Table LXI.

TABLE LXI
Percentage composition of "white micas"

	1.	2.	3.	4.	5.	6.	7.	8.
SiO ₂	45.2	44.68	46.54	48.39	47.89	49.49	47.86	48.10
Al ₂ O ₃	38.5	31.80	36.37	34.64	37.32	25.48	36.03	33.51
Fe ₂ O ₃	—	4.49	0.72	1.15	0.47	4.89	0.10	0.15
FeO	—	0.84	0.36	0.27				
MgO	—	1.30	0.50	0.44	0.37	2.72	0.54	0.80
MnO	—	0.04	nil	nil	—	—	—	—
TiO ₂	—	0.70	0.17	0.11	—	—	—	—
CaO	—	0.52	0.22	0.26	0.40	0.34	0.58	0.87
BaO	—	0.23	—	—	—	—	—	—
SrO	—	0.04	—	—	—	—	—	—
K ₂ O	11.8	10.48	8.06	7.82	1.79	5.86	6.78	6.78
Na ₂ O	—	0.79	0.46	0.22	3.17	0.15		
H ₂ O + 105° ..	4.5	3.50	6.31	6.07	n.d.	6.66	7.59	9.00
H ₂ O - 105° ..		0.28	0.52	0.44	n.d.	2.31		
F	—	0.11	0.02	0.06	—	—	—	—
P ₂ O ₅	—	—	0.06	0.06	—	—	—	—
	100.00	99.80	100.31	99.93	91.41	99.19	100.00	99.99

- 1.—"Theoretically pure" muscovite: empirical formula $2H_2O \cdot K_2O \cdot 3Al_2O_3 \cdot 6SiO_2$.
- 2.—Robust muscovite in a granite pegmatite, Malvern Hills. Analysed by Dr. A. W. Groves (Brammall & Leech, 1937).
- 3.—Hydromuscovite: a soft, silver-white variety of sericite associated with quartz, pyrite, and arsenopyrite in veinlets near surface at Ogofau, Carmarthenshire. Analysed by Miss H. Bennett, M.A., B.Sc. (Brammall & Leech, 1937).
- 4.—Hydromuscovite: a variant from No. 3, occurring as a veneer on shear-planes underground—as at colliery A. 2, South Wales.
- 5.—Sericite admixed with kaolinite—occurring as a veneer on joint- and shear-planes at colliery A.2, South Wales. Analysed by Geochemical Laboratories, London.
- 6.—Computed "mean composition" for A.2 sericite in general.
- 7.—Computed "mean composition" for A.3 sericite in general.
- 8.—Illite: average composition of four illite-rich fractions isolated from shales, (Grim & Allen, 1938).

The composition of primitive mica is liable to adjustment as compaction proceeds. Moreover, growth extension oversteps and enmeshes minute alien particles; hence, even the smallest flakes are habitually riddled with inclusions (Plate E VI, Fig. A). Water-elutriated flakes tend to become filmed with hydrated ferric oxide (Plate E VII, Figs. 1 and 2); this is possibly due to the oxidation of ferrous iron indigenous to the mica-mass, though it may conceivably represent a precipitation from the water itself. It follows that no "standard mica composition" is applicable to all the South Wales shales. The composition of "theoretically pure" muscovite is rarely, if ever, attained by the actual modal species.

Kaolinite, mica, and quartz are the chief identifiable silica-minerals in all these shales. But attempts to compute an actual (modal) mineral-composition consistent with any particular shale-analysis encounter numerous embarrassments:—

(a) "Potash percentage" in mica is very variable; that in the rock as a whole is not safely assignable to mica alone; groundmass units still imperfectly known claim some proportion of both potash and soda—the latter preferentially.

(b) Assignment of alkalis to mica exclusively entails unduly large allotments of alumina and silica to this mineral. Both alumina and silica are claimed by groundmass units of uncertain composition.

(c) Magnesia and ferrous oxide cannot be excluded from the mica-composition, though the proportions in which they are allotted to mica and other substances must, for the present, rest on a somewhat arbitrary basis.

(d) Alumina and silica in excess of allotments to mica invite the assumption that, if kaolin be computed, any ultimate "excess silica" may be assigned to quartz.

A normative composition thus computed disposes arbitrarily of problems inherent in the groundmass-constitution. Nevertheless, some such tentative computation is desirable for comparative purposes: the results are compared with the modal composition so far as this may be determinable, and any adjustments inferred to be necessary are instructive. Many computations of this kind have been made, and inferences drawn from them have been applied to the interpretation of the rock-suites as a whole; their publication here, however, would serve no immediately useful purpose.

Where an approximate modal composition is unobtainable by microscopy alone—as is largely the case with mine-dusts—some normative basis must be adopted, with the object of determining at least a maximum and a minimum figure for each of the three chief minerals. This has been done by Dr. Nagelschmidt, using X-ray data as an aid to the assessments.

Quartz (primary and secondary)

All the strata examined contain some proportion of primary (detrital) quartz, recognizable as such with reasonable certainty. The quantity of detrital quartz varies from stratum to stratum, and from layer to layer.

Though "total free silica" in an average sample is determinable with a fair degree of accuracy, the percentage figure gives no clue to the presence or absence of secondary silica, which may be crystalline (quartz) or chalcedonic (secondary quartz in an opaline matrix), or essentially amorphous—some form of hydrated silica.

Secondary quartz appears in the groundmass of shales and in the interstitial shale-substance of quartz-rich bands, such as the "strong cliff" at colliery A.3 (Stanlyd seam). It may also develop as marginal outgrowth from detrital quartz. It originates as exceedingly small nuclei, which are very difficult to detect, in the tawny dust-speckled groundmass-plexus (Plate E VII, inset

circle). Its genesis and development are largely incidental to the evolution and growth of other secondary species—notably mica (Plate E IV, Fig. c; Plate E VI, Fig. d).

Quartz nuclei have the amoeboid habit; with further growth, they become more globular, with indefinite, frayed and teased-out margins. At a later stage, this delicate marginal structure integrates to a physically continuous growth-zone with a minutely crenulate, lobate, or digitated outer margin.

The amount and grain-size of both secondary quartz and secondary mica appear to be roughly proportional to the degree of compaction attained. The A.1 shale is appreciably more quartzose than the A.3 shale; but whether it is the richer in secondary quartz is uncertain. In both these shales, obscure and unidentified groundmass material is still abundant, and its composition is probably potential towards "a little more mica, more quartz, and a specific chlorite as yet unborn".

Measurements of particle-size for quartz in mine-dusts, made by Dr. Bedford and Dr. Warner on preparations supplied by Dr. Nagelschmidt, support an expectation that in the A.1–A.3 suites the percentage of the larger sizes should be appreciably greater than in the S.4–B.3 suites.

Primary siderite, and "mixed" carbonate

Siderite-rich "mixed" carbonate, typified by ankerite and "black-band ironstone", is habitually present in coal-bearing horizons. We may safely assume that the water from which the primitive carbonaceous muds were sedimented was appreciably acid. As $\text{Fe}(\text{OH})_2$ is precipitated from dilute simple solutions at about pH 5.5, the carbonate, FeCO_3 , could begin to form at about this pH level.

Initially, such precipitations are essentially colloidal. Siderite showing the coccolithic (colloform) habit is common in the S.4–B.3 suite, and is conspicuous, even in hand-specimens, in the B.3 shale (Plate E II, Fig. A) where laminae and lenticular bands of coccolithic, almost pure, siderite have responded to compaction and deformation similarly to shale laminae above and below them. Such siderite must be regarded as primary (in the sense that it originated in the pre-compaction stage).

In the A.1, A.2 and A.3 shales, the coccolithic habit is rarely recognizable: the carbonate has undergone recrystallization, in isomorphous admixture with calcite and magnesite, the latter being probably introduced by "late" magnesium metasomatism. Comparative analytical data for the "ankerites" of the coal-field might establish some relationship between shale-facies and magnesium metasomatism.

As $\text{Mg}(\text{OH})_2$ is not precipitated from dilute simple solutions below about pH 9.5, direct precipitation of the basic carbonate (or even the basic silicate) would tend to be delayed in the primitive swamp-waters. Even in mudstones and low-grade shales, adsorbed magnesia should retain a considerable degree of mobility, with freedom to transfer itself from one to another term in a sequence of transient mineral-complexes capable of "base-exchange" behaviour, e.g. beidellite, and even less definitely specific mineral substances. Actually, magnesia is finally "fixed" (in partnership with ferrous oxide) in the more permanent phase chlorite, which attains robust crystallinity in the slate stage.

The same kind of "freedom" may be conceded to lime in excess of equilibrium requirements for carbonate, and to alkalis in excess of requirements for mica-growth actually in progress.

It is significant that base-exchange concerns mainly alkalis, lime, and magnesia.

Base-exchange capacity (see Appendix I, Table CVII, p. 217)

The alkalis readily released to aqueous diethylamine are attributable, in part only, to salines, chiefly sodium chloride; some proportion of these alkalis is leached from base-exchange positions in silicate-substances which are not necessarily as "specific" as montmorillonite or beidellite. Shales and their "fine fractions" leached of mobile alkalis by diethylamine solution (or,

PLATE E II



FIG. A. Colliery B.3 shale, showing laminæ and lenticular bands of coccolithic, almost pure, siderite, which have responded to compaction and deformation similarly to shale laminæ above and below them ; see p. 132.

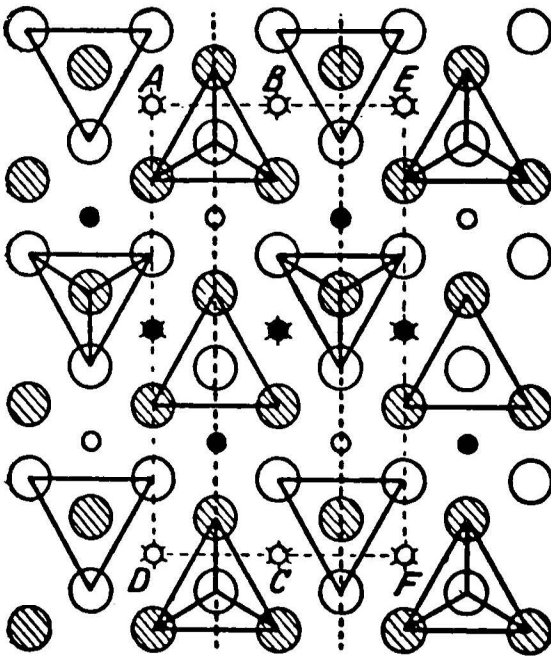


FIG. B. Diagram of atomic lattice pattern of common olivine, $(\text{Mg, Fe})_2\text{SiO}_4$; see p. 140. From Bragg, W. L. (*Z. Krystallogr.*, 1930, 74, 242.)

more thoroughly, by water-elutriation) still retain a moderate base-exchange capacity (22-46; *cf.* water-elutriated montmorillonite, and beidellite, B.E. 88-122), Table LXVIII.

Groundmass constituents

The purpose of the South Wales inquiry as a whole served in some measure to define the nature of the mineralogical data which would be specially relevant: the aim of this aspect of the work was to decide whether differences in mineral assemblage could be co-ordinated with differences in the incidence of pneumoconiosis at the various mines.

Had granites, or any other coarse-grained holocrystalline granulose rock-type, been the material concerned, the mineral phases to be accounted for would have included few, if any, unknowns. Slates are holocrystalline, but they are neither coarse-grained nor granulose: the "mesh" or "flake-and-fibre plexus" is the dominant fabric element. Nevertheless, no major, and few (if any) minor constituents in slate would be likely to escape identification.

Shales are of still finer texture, and the flake-and-fibre fabric prevails. Moreover, not all the shale-mass is robustly crystalline. Though holocrystallinity would doubtless be conceded on X-ray criteria alone, some proportion of any typical shale-mass would rank as obscurely crystalline, dubiously "specific", and of conjectural composition.

Such difficulties of petrological diagnosis approach a maximum in the case of clay substances—the ultimate products of the weathering process—, which account for a large proportion of the primitive sediment from which shales evolve.

The essentially amorphous "mineral complex" indigenous to clay may also be "inherited" by primitive shale (typified by "mudstone"), and inheritance of this kind must necessarily be taken into consideration. Early evolutes from such material include mica, kaolin, and commonly also some beidellite term; unindividualized residuum thus ranks as "lag", and constitutes the "ultimate groundmass" already mentioned (p. 128).

Petrological inquiry in the present case is concerned with the gradation of progress in the direction clays → shales → slates, using criteria based on a gradual differentiation of obscure mineral matter into "parcels" which, by virtue of composition and appropriate relative concentration of components, may become the foci of new crystal growths. We have to consider how far this focal segregation has proceeded in particular shale-facies.

The particular mineralogical perplexities surrounding the constitution of the groundmass arise largely from two facts: (a) the level of minimum reactivity of silica is about pH 7 and only above this level can it assume the acid role; (b) the level of minimum reactivity for alumina is about pH 6; i.e. it can function as a base when silica is unable to act as an acid and therefore cannot combine chemically with alumina (or ferric oxide) to form true "silicates". Pending the results of further investigation, the following possibilities regarding the constitution of the groundmass may reasonably be considered:

Below pH 7:

- (a) Unstable water-soluble aluminates of the general type $RO \cdot Al_2O_3$ or $R'_1O \cdot Al_2O_3$.
- (b) "Mixed" coagulum of the generalised type $mAl_2O_3 \cdot nFe_2O_3 \cdot pSiO_2$, with bases mainly "adsorbed" but more firmly attached to alumina than to silica.

Above pH 7:

Complex systems engaging all these substances, and liable to progressive reconstruction—under conditions favourable to dehydration, decarbonatisation, and silication—towards the achievement of crystalline alumino-silicates, some of which are well-known, others obscure.

From this viewpoint, the groundmass problem presents a sequence of mineral compounds with unknown chemical (and *in vivo*) reactivities, but in parental relationship to familiar minerals such as mica, kaolin, beidellite, quartz, and chlorite.

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That the groundmass merits further study is indicated by the following results of preliminary test-work carried out for us by Geochemical Laboratories, London (see also Appendix I, p. 214.)

Differential solubility in 2 : 1 aqueous diethylamine :

(a) 10 g. portions of stock samples of the shales release from 0.03 per cent. to 0.09 per cent. of their mass as free soda and potash.

The yield rises from a minimum for B.3. to a maximum for A.3, the sequence being approximately in the group order set out in Table LXII.

(b) 0.5 g. portions release 0.3 per cent. to 6.9 per cent. of their mass as filter-passing "disperse colloid" silica and alumina.

The yield is again a minimum for B.3, the maximum being credited to S.4.

Table LXII shows that the silica and alumina extracted cannot be summarily attributed to the dissolution of sericite, quartz, and kaolin alone, but it suggests that the responsive substances include "non-specific" solids in which alumina and silica are less firmly combined than in either sericite or kaolin.

TABLE LXII

Sample	Percentage of 10 g. sample extracted as alkalies	Percentage of 0.5 g. sample extracted as $\text{SiO}_2 + \text{Al}_2\text{O}_3$
<i>Clods :</i>		
A.3	0.09	4.2 in mol. ratio $\text{SiO}_2/\text{Al}_2\text{O}_3$ 1.5
A.1	0.06	n.d.
A.2	0.05	1.6 " " " 1.5
S.4	0.05	6.9 " " " 1.7
B.2	0.04	n.d.
B.3	0.03	0.3 " " " about 2.0
<i>Minerals :</i>		
Sericite .. (0.5 g.)	—	0.1 " " " 1.0
(A.2 var.)	0.4	0.2 " " " "
Quartz .. (0.3 g.)	—	0.2 " " " "
Kaolin .. (0.5 g.)	—	About 0.4 " " " n.d.

Gels :

Freshly prepared silica gel, and alumina-silicic gels for which the mol. ratio $\text{SiO}_2/\text{Al}_2\text{O}_3$ ranges from 1.15 to 1.63, are completely soluble. As this ratio rises, the amount of silica extracted also rises—but only slightly: there is definite evidence that the alumina acts "protectively" towards the silica.

TABLE LXIII

The mutual precipitation of colloidal silica and alumina

Shale sample	Extracted by 30 ml. of 2 : 1 aq. diethylamine in 3 hours.					
	From 0.5 g. sample.		From 1.5 g. sample.		From 10 g. sample.	
	SiO_2 g. $\times 10^4$	Al_2O_3	SiO_2 g. $\times 10^4$	Al_2O_3	SiO_2 g. $\times 10^4$	Al_2O_3 Alkalies* g. $\times 10^4$
A.3 ..	100	111	282	325	nil	2 86
			i.e. nearly three times the quantities yielded by 0.5 g.		i.e. negligible, as also in each of the remaining cases.	
A.1 ..		n.d.		n.d.		65
A.2 ..	43	29		n.d.		52
B.2 ..		n.d.		n.d.		39
B.3 ..		n.d.		n.d.		32

* Alkalies are continuously extracted and pass into the filtrate.

Silica and alumina *appear* to accumulate, without much tendency towards mutual precipitation, until some critical concentration is attained, when mutual precipitation occurs and reduces the quantity of filter-passing colloid to a negligible amount.

When only 0.5 g. samples are used, the filter-passing quantity of colloids appears to approximate closely to the quantity actually released by the sample.

At first sight, these results suggest that the molecular ratio in which silica and alumina are released by samples is more likely to be gauged by test-work on 0.5 g. (or even smaller) samples. But the results are qualified (for the time being) by two facts: (a) The 10 g. sample was not tested at the same time as the 0.5 g. and 1.5 g. samples; nor was the former as homogeneous (in respect of grade-size) as the latter—a fact noticed by Geochemical Laboratories, who have since confirmed the importance of "grade-size" standardisation in comparative work with aqueous diethylamine; (b) the quantity of filter-passing sols is governed by several factors still unassessed.

The few results obtained in this exploratory work support the view already expressed, that the unequilibrated constituents of shale-groundmass include an "overload" of alumina awaiting combination in more definitely specific minerals.

We venture to suggest that, in non-anthracite shales, the quantity of such per-aluminous mineral matter, with associated "free hydrated ferric oxide", may act counter to any pneumokoniosis factor possibly attributable to secondary quartz—present as yet in only small amounts.

(B.) PETROLOGICAL DETAIL

In this section the petrological data for the shales are set out in the form of a tabular specification. Below are some general observations concerning the shale fabric; and these are followed by summaries of the petrological characteristics of the two groups of samples, Group I being those from the non-anthracite mines, and Group II those from the anthracite mines.

Shale fabric (general observations)

Insets: Relatively conspicuous flakes, fibres and grains set in a dust-speckled matrix.

Matrix: An intricate mesh-work or plexus of extremely minute flakes and fibres enmeshing particulate coaly matter, carbonate, pyrite, rutile, quartz, etc., cemented by a subordinate amount of more homogeneous "ultimate groundmass" substance; the latter, though not specifically determinable under the microscope, is doubtless obscurely crystalline, and necessarily changes in bulk-composition as its amount is reduced by the evolution of determinable species such as mica, kaolin, and quartz.

Original bedding: Usually well preserved, except in the plastically deformed and sheared A.2 shale and in occasional bands of the A.1 and A.3 shales.

Relatively minor deformation has been observed in the B.3 shale; few sections of the S.4 and B.2 shale show this feature.

Pressure-induced parallelism of flake-and-fibre units conformably with bedding is best developed in the A.1 and A.3 shales. Parallelism in the A.2 shales is largely a secondary feature, often unrelated to original bedding: it is mainly attributable to shearing.

Grade sequence: The grading inferred is based on somewhat fine distinctions, some of which are still provisional. They include differences in degree of compaction, pressure-induced parallelism, growth detail and robustness of crystallinity shown by secondary minerals such as mica, quartz, carbonate and pyrite. The grading takes into account also the relative amount of discernible "free" hydrated ferric oxide, as well as analytical data for the proportion of ferric oxide relative to ferrous oxide which could not be accounted for in pyrite and carbonate.

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Group I (non-anthracite) shales—Collieries S.4, B.2 and B.3 (see Plate E III)

Secondary :

Quartz : Difficult to establish, except in occasional shale-particles at high magnification and in residues from acid-treated shale-powders.

(Primary detrital quartz calls for no special comment.)

Mica q An "illite" variety ; usually ill-defined in outline ; often so clouded with dust-fine inclusions as to be almost indistinguishable from groundmass except between crossed nicols.

Beidellite and kindred : Probably present, together with other less specific complexes responsive to base-exchange conditions (see under "Groundmass" below).

Kaolin and kindred : Assessed as "general, often abundant" in these shales.

A dickite-like mineral is both abundant and conspicuous in the B.3 shale ; inconspicuous and less abundant in the B.2 shale ; not yet established for the S.4 shale.

Halloysite is considered to be present ; it is probably antecedent to kaolin and the dickite-like mineral, from which it differs in being more hydrous and of less robust crystallinity.

Groundmass :

Composed of the smaller grade-sizes of the minerals listed above (and below) ; mica in particular commonly shows "seriate" growths.

The ultimate groundmass is probably a complex of obscurely crystalline (non-specific) substances, composed of loosely combined hydrated silica, alumina, and ferric oxide, with feebly combined or merely adsorbed bases.

Such mineral matter would respond to base-exchange conditions.

Tentative tests with "extractors" (acid, alkali, and aqueous diethylamine) indicate that the groundmass as a whole is richer in ferric oxide, poorer in ferrous oxide, and more aluminous than the groundmass of Group II shales.

Free ferric oxide, in the hydrated form, is usually conspicuous, but of patchy distribution.

Free alumina, in the hydrated form, is considered to be present, also water-soluble aluminates.

Carbonates : Siderite, ankerite, and (more rarely) calcite. A B.3 aggregate of nearly pure siderite retains a primary coccolithic (colloform) habit (Plate E II, Fig. A).

Pyrites : *Minor accessory species* include detrital muscovite, albitic feldspar, chlorite (definitely altered biotite), rutile, some member of the epidote group, zircon, gypsum (very rarely noticed), and several others of casual occurrence and in quite negligible amounts.

Group II (anthracite) shales—Collieries A.1, A.2 and A.3 (see Plate E IV)

Secondary :

Quartz : Common and unambiguous (Plate E VII, inset circle) ; grade-size from 13μ downwards ; good studies occur in the interstitial shale-matter in the "strong clift", A.3 (Stanlyd) (Plate E VI, Fig. D).

Minute pools of secondary-quartz mosaic, and "moats" of similar quartz occur round pyrite, carbonate, and coaly matter in some sections of A.1 shale.

A.2 samples do not provide unambiguous studies.

Mica : Mica in the body of all the shales appears to be the normal variety, i.e., dominantly potassic. Flakes are habitually riddled with inclusions ; "seriate" growth is clearly shown (Plate E VI, Fig. D).

An A.2 variety (Plate I) precipitated from aqueous solutions on joint- and shear-planes is dominantly sodic, and exceptionally free from inclusions. No comparable variety has been recorded*.

Beidellite and kindred : Observations, as in Group I.

Base-exchange data :		B.E. capacity
A.3 clod	Mass sample	69
	After four extractions with aqueous diethylamine ..	32
A.2 clod	Mass sample	33

Chlorite : A primitive ferruginous variety which is of "evolute" status has been observed in both the A.1 and the A.3 shales. In A.2 shales, where such chlorite would be expected, the criteria for secondary status are obscured by shearing.

Kaolin and kindred : Assessed as appreciably less abundant than in Group I shales. The dickite-like mineral listed under Group I has not been observed.

Groundmass :

The groundmass of these shales is more "populous" with definitely crystalline units than that of Group I shales (cf. Plates E III and E IV).

Comminution by shearing has reduced the grade-size of units in the A.2 shale.

The groundmass of the A.1 and A.3 shales is more siliceous, richer in ferrous oxide than that of Group I shales. The ultimate groundmass appears to be a diminishing quantity—though it may amount to about 20 per cent. of the shale-mass. It probably approaches the composition of "chlorite + a little supplementary mica + considerable quartz."

Free ferric oxide, in the hydrated form, is very scanty. The reduction of ferric to ferrous oxide, especially in the presence of dispersed carbon, is one consequence of high-grade compaction.

Free alumina, in the hydrated form, is unlikely to be present.

Carbonates : Ankerite is prevalent. Calcite occurs in the "strong cliff" (and joint-planes) at colliery A.3 (Stanllyd).

Minor accessory species : As for Group I ; there is no obvious difference between assemblages isolated from the two Groups.

III.—MINE-DUSTS

(A.) THEIR COMPOSITION COMPARED WITH THAT OF STRATA

Comparison of rock-analyses on the primary basis of silica-percentage for the anhydrous material—with or without the previous elimination of normative pyrite, carbonates, etc.—yields a tabulation-queue of strata, mine-dusts, etc., in heterogeneous sequence having little co-ordinating value.

On the other hand, computation to the molecular ratio basis
 mols. SiO₂ : Σ bases (=1,000 mols.)

yields a tabulation which not only immediately reveals the mass-concentration of "total silica" relative to a fixed quantity of bases, but also shows that, in respect of silica-content, mine-dusts are intermediate between strata and fusain. This method of computation also assists comparative work on the variation of bases *inter se*. It is illustrated by Table LXIV. This method is an adaptation of "the Niggli numbers" sometimes applied to similar comparative work in other branches of petrology.

* Soda-illite : see footnote on p. 126.

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TABLE LXIV

Comparative analytical data for selected strata, "whole-seam" ash, and "mine-dust" ash

Material analysed.	Coal	Mols.	Mols. of bases (to basis 1,000)					
	Rank.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O
<i>Strata.</i>								
†A.3 (Stanlyd Seam), hard fireclay	A	3773	683	56	80	38	42	101
†A.3 (Stanlyd Seam), strong cliff..	A	3204	650	76	90	29	45	111
*B.2, Clod, top of seam ..	B	3171	767	10	67	16	36	103
†A.3, P. ..	A	2843	665	83	65	33	45	110
*B.3, Roof, 1st rippings ..	B	2720	717	30	79	24	26	124
†A.3 (Stanlyd Seam), Clod C. ..	A	2415	678	48	110	3	51	110
*A.2, clod ..	A	2329	611	73	120	14	107	75
*B.3, clod, top of seam ..	B	2188	695	46	98	18	30	112
<i>*Ash of Mine Dusts :</i>								
B.2 .. 1C1 ..	B	2033	668	45	74	91	32	91
S.4 .. 1U1 ..	S	1964	522	91	82	214§	19	72
A.3 .. 2H2 ..	A	1793	697	54	79	97	36	38
S.4 .. 2U1 ..	S	1778	558	36	22	247§	78	60
B.1 .. 1A1 ..	S	1761	616	70	93	148	18	55
A.6 .. 2R2 ..	A	1737	614	94	105	89	23	75
S.3 .. 1E1 ..	S	1701	555	53	75	221	20	75
A.3 .. 2H1 ..	A	1683	572	59	61	201	47	59
A.6 .. 2R1 ..	A	1613	610	83	105	96	33	72
Wat. .. 1A2 ..	B	1607	391	252	107	145	36	68
A.3 .. 3H1 ..	A	1566	682	72	72	125	18	31
A.1 .. 2M1 ..	A	1465	404	118	181	197	52	48
A.2 .. 2S1 ..	A	1397	450	131	178	160	25	57
A.8 .. 2N1 ..	A	1348	654	53	84	151	33	26
B.3 .. 1B1 ..	B	1335	453	39	70	357§	15	66
A.5 .. 1D3 ..	A	1290	556	111	109	167	27	31
A.2 .. 1S1 ..	A	1289	576	96	122	132	37	37
A.1 .. 2N2 ..	A	1242	430	143	173	175	40	40
S.5 .. 1T1 ..	S	1237	366	25	4	545§	14	47
A.5 .. 1D1 ..	A	1234	487	123	118	194	38	36
<i>†Ash of "Whole seam" (sample Coal Survey Lab., Cardiff) :</i>								
A.3, 12 Dist., 91 (1), Ash, 4.50 per cent. ..	A	1097	522	189	63	173	38	16
A.1, 12 Conveyor, 94/LP, 2.54 per cent. ..	A	1093	532	80	106	170	85	27
A.2, 5 Dist., 95/LP, 2.60 per cent. ..	A	1076	592	97	81	149	64	17
A.3, 28 Dist., 91 (1), 3.50 per cent. ..	A	797	392	286	104	167	41	10
S.4, 2 ft. 9 in. South, 85/2 ft. 9 in., 2.34 per cent. ..	S	740	389	306	161	102	28	14
<i>*Ash of Mine Dust :</i>								
Wat. .. 1A3 ..	B	699	295	270	148	243	10	34
A.2 .. 2S2 ..	A	668	267	149	259	292	22	12
B.3 .. 1B3 ..	B	578	169	31	55	712§	8	24
B.3 .. 1B2 ..	B	303	101	18	32	829§	6	13
*A.2, mica-rich film-and-crust ..	A	1758	805	5	20	16	113	42
*C.f. Witwatersrand, Basket ground-mass ..	—	2826	533	112	166	62	20	107

* Analyses by Geochemical Laboratories London.

† Analyses by Coal Survey Laboratory, Cardiff.

‡ Analyses by W. H. Herdsman, Glasgow.

§ High CaO-content due mainly to limestone-dusting.

Coal rank : A = Anthracite.

B = Bituminous coal.

S = Steam coal.

(B). SPECIAL CONSIDERATIONS IN RELATION TO THE PNEUMOKONIOSIS PROBLEM

The chemistry of the mine-dusts has been dealt with in detail by Dr. Nagelschmidt, but it may not be inappropriate to consider here certain subsidiary questions which may have a bearing upon the action of the dusts when inhaled into the lungs.

1. The "Acidity" of Quartz

In view of the stress frequently laid on the actual percentage of "free silica" (as quartz) in mine-dusts and strata alike, we deemed it prudent to ascertain whether quartz does, in fact, behave, to any significant extent, as "silicic acid anhydride" at ordinary temperatures. Our colleague Dr. G. van Praagh (1939) investigated this question and concluded that the apparent acidity of finely powdered quartz is attributable mainly, if not entirely, to carbon dioxide dissolved in an extremely thin layer of water adherent to the surface of each quartz particle.

2. The Response of Mineral Powders to Physiological Salt Solution

Stress has also been laid on the relative water-solubilities of finely particulate minerals. We suggest, however, that the solubility of powdered minerals in pure water is less relevant to the problem of pneumokoniosis than their response to liquids more nearly related to tissue-fluids—in particular, their virtual "dissolution", involving the release of bases, silica, etc., to the complex physiological environment.

It is known that silica is soluble in a solution of sodium chloride. No precise information being available concerning the response of particulate quartz to a solution comparable with a body-fluid, the following experiment was carried out (before this inquiry began), in collaboration with Dr. Max. H. Hey, Assistant-Keeper in the Natural History Museum, South Kensington.

Finely-divided Brazilian Pebble was exposed to a standard Ringer-Locke solution in a platinum bottle, maintained at a temperature of $37^{\circ} \pm 3^{\circ}$ for 1,000 hours, while bubbles of CO_2 were released in the solution at regular intervals.

The fluid, at first persistently cloudy owing to the gelatinisation of colloidal silica, was filtered and transferred to a stoppered bottle well lined with paraffin-wax.

During a period of three months, the clear filtrate again became cloudy, and this suspension also was removed by filtration.

After a further period of three months, a perceptible cloudiness once more developed, and was again removed by filtration.

The final filtrate was analysed for silica-content by Dr. E. J. King, British Postgraduate Medical School, London, who centrifuged the fluid before estimating the silica colorimetrically. The clear liquid was found to contain 42 parts/million silica.

This solubility-figure is in close agreement with data for the solubility of "silica" in carbonate solutions alone. It refers solely to the amount of silica remaining in the centrifuged fluid after two perceptible precipitations of silica hydrogel had formed and had been removed by filtration. Whether this silica is in the physical state of true solution, and identical with the "toxic silica" described by Gardner (1937) as a "dispersed colloidal solution" is uncertain.

Parallel test-work was done on other common rock-forming minerals in the finely powdered state. The results indicated the breakdown and partial dissolution of these minerals in physiological (and other) saline solutions. Data selected as being relevant to the present inquiry are included in Table LXV.

TABLE LXV

	Mol. ratios :	
	SiO_2/Al_2O_3	SiO_2/Fe_2O_3
I.—Response of finely powdered mineral-silicates to Ringer-Locke physiological salt solution (2 litres) maintained at blood temperature ($\pm 8^\circ$) in a fused-silica flask, fitted with dust-trap, for about 1,000 hours :		
1.—An alumina-rich hornblende :		
Original mineral (a)*	5.25	13.8
Silt-grade residuum after being washed free from chloride (b)	4.71	15.0
2.—An alumina-poor augite :		
Original mineral (c)	14.7	23.1
Silt-grade residuum after being washed free from chloride (b)	13.9	22.4
3.—Feebly aluminous olivine :		
Original mineral (c)	—	13.8
Silt-grade residuum after being washed free from chloride (b)	—	22.4
II.—Response of hydromuscovite ("sericite") to N/5 NaCl-solution maintained at 80° – 90° C. for 28 days :		
Original mineral (d)	2.47	—
Silt-grade residuum after being washed free from chloride (e)	1.92	—
III.—Response of an alumina-rich chlorite to electro-dialysis in fused-silica apparatus fitted with anti-dust cover :		
Original mineral (a)	2.82	21.9
Silt-grade residuum after being washed free from chloride (a)	2.65	16.4

* Analysts : (a) W. J. Dunstall, A.R.C.S., D.I.C.
 (b) Geochemical Laboratories, London.
 (c) W. H. Herdman, Glasgow.
 (d) Miss H. Bennett, M.A., B.Sc.
 (e) Dr. A. W. Groves.

Thus, the propriety of taking into account "total" bases, irrespective of their distribution among normative or modal minerals, is stressed by their individual and collective behaviour when finely powdered minerals are exposed to standard physiological salt (or other saline) solutions, which initiate destructive change and dissolution—involving hydration, oxidation and the leaching of bases, as in weathering and doubtless also in reactions *in vivo*.

3. Enhancement of the Reactivity of Mineral Silicates by Grinding

It is known that grinding (pulverization) enhances the reactivity of mineral silicates to aerated water. The particular case of olivine, which belongs to the simplest of the silicate-structures, will serve to explain this general mechanism.

Common olivine is a solid solution of forsterite and fayalite. Its formula is conveniently written thus: $(Mg,Fe)_2SiO_4$. Its atomic lattice-pattern is illustrated diagrammatically in Plate II, Fig. B (facing p. 132). The tetrahedral (SiO_4)-units are set out singly, but are aligned in parallel blocks, in such a manner that the separate units in any one block are "upside-down" relative to those in the flanking blocks. Moreover, the blocks themselves are staggered alternately backwards and forwards. The detached tetrahedra are held together in a geometric pattern by the Fe and Mg atoms, which are distributed at regular intervals along the avenues between the tetrahedra. Each Fe and Mg atom thus lies between six O-atoms, made up of pairs belonging to three separate tetrahedra. These six O-atoms may be regarded as occupying the six solid corners of an octahedron having an atom of Fe (or Mg) at its geometric centre. This octahedral unit constitutes the (MgO_6) group.

Rigidity for the lattice-structure as a whole is secured by valency-bonds, which, however, differ in strength :—

(a) Within the (SiO_4) -tetrahedron, the bond between the Si-atom and each of the four O-atoms is "strong", being of unit strength.

(b) Within the (MgO_6) -octahedron, the single divalent Mg (or Fe) atom is tethered to each of the six O-atoms; hence the bonds are "weak", averaging only "one-third unit" strength.

Hence, grinding disrupts the lattice selectively—where the bonding is weak, i.e. along the avenues populated by Mg and Fe atoms. The (SiO_4) -units are not, in fact, disrupted. But the six weak bonds tethering the (MgFe) -atoms are severed erratically: momentarily at least, any one such atom may become "untethered" along one or more of its six bonding-lines. Hence some fraction of its positive charge may be momentarily "free", and the atom concerned is then specially prone to accept cancellation of its "free" charge by any negatively charged anion available, e.g. (OH) , (CO_3) , (HCO_3) , (SO_4) , Cl, etc. This chemical reaction is exothermal in character.

Under laboratory conditions an aqueous extract of olivine is alkaline and may contain the following :—

$\text{Mg}(\text{OH})_2$ —alkaline in aqueous solution, but having only about 1/1,000 the solubility of $\text{Ca}(\text{OH})_2$.

$\text{MgCO}_3 \cdot 3\text{H}_2\text{O}$ —also alkaline in aqueous solution, but about fifty times more soluble than $\text{Mg}(\text{OH})_2$.

$n\text{Mg}(\text{OH})_2 \cdot m\text{MgCO}_3 \cdot 3\text{H}_2\text{O}$ —the hydrated basic carbonate, slightly soluble, and also alkaline in aqueous solution.

$\text{Fe}(\text{OH})_2$ —colloidal; unstable and quickly oxidized to the ferric hydrate.

FeCO_3 —usually slightly hydrolysed even at the instant it is produced—either directly from the hydrate or by the breakdown of the soluble bicarbonate, $\text{Fe}(\text{HCO}_3)_2$. Both these carbonates are readily oxidized (with elimination of CO_2) and yield the brown hydrogel, hydrated ferric oxide.

A relatively small amount of colloidal silica is also released—initially as the sol, but liable to coagulation to gel by the soluble electrolytes mentioned above.

IV.—PNEUMOKONIOSIS INCIDENCE IN RELATION TO PETROLOGICAL DATA

The incidence of certified silicosis is much greater in the anthracite than in the non-anthracite mines, and Hart and Aslett, in their medical survey, have shown that there is some degree of correlation between the rank of the coal mined and the incidence of pulmonary X-ray abnormalities in the miners. The incidence of radiological abnormalities tends to increase from low at the bituminous end of the scale of coal rank to high at the anthracite end; and the change in incidence is gradual as one passes from the lowest rank of the coalfield, namely, bituminous coal, through semi-bituminous coal, and low rank anthracite to high rank anthracite. Although a relationship is thus suggested between the incidence of pulmonary abnormalities and rank of coal, Hart and Aslett stress that it should not be inferred that it is differences in the coal itself that produce the differences in incidence. Some other variable, correlated both with rank of coal and with incidence of pulmonary abnormalities, may be responsible.

It is generally agreed that anthracite is derived from the same original material as the other coals, and it is supposed that the special properties of anthracites are due to the fact that they have been subjected to greater compression than other coals, and that the effects of pressure have been amplified by the increase in temperature due to the depth to which the seams have been buried. Thus, differences in rank of coal are closely correlated with differences in the degrees of geological compression.

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Increased compression, aided perhaps by enhanced temperature, would also, with the passage of time, bring about changes in the nature of the rocks associated with the coal seams. In an earlier publication, Cox (1938), after a careful study of geological conditions in the working places of the South Wales mines, and taking into consideration the statistical evidence available at the time (1933), concluded that the incidence of silicosis amongst coalface workers was related to "the presence of free silica in the shales that accompany the coals, and, in particular, to an increased content of secondary silica in the shales of those areas that have been subjected to the greatest geological compression."

We are in entire agreement with Cox's outlook on the facts of metamorphism; and our findings in the present study confirm and amplify his expectation concerning graded metamorphic effects. In a footnote, Cox (*loc. cit.*, p. 165) refers to the volume of evidence adduced by W. R. Jones (1933, 1934) as to the possibly harmful character of dusts containing sericite. He co-ordinates Jones' evidence with his own conclusions by remarking that "the amount of sericite will be increased in those shales that suffered the greatest compression". With this co-ordination also we agree.

Our investigation shows that with the transition from bituminous coal to high grade anthracite there are to be found (a) increasing signs of compression effect in the shales that form the clods and roofs, (b) an increase in the content of secondary quartz and mica, and (c) higher grade differentiation effects in the groundmass.

Between the two groups of rock samples studied, viz.: those from the non-anthracite mines S.4, B.2, and B.3 on the one hand, and those from the anthracite mines A.1, A.2 and A.3 on the other, there are in the shales strong mineralogical and textural contrasts, due to changes in the latter wrought by pressure. Parallel with these contrasts, there are broad differences in the incidence of pneumokoniosis, for in the non-anthracite mines the incidence is low, while in two of the anthracite mines included in our study, collieries A.1 and A.3, it is high.

At the other anthracite mine, A.2, there is a low incidence of pneumokoniosis, and it is of interest that the samples from this mine differed in certain respects from those from collieries A.1 and A.3. In the samples from the two latter collieries relatively advanced metamorphic changes were evident. On the other hand, the general appearance of the samples from colliery A.2 had many features in common with "fault-gouge" peculiar to phyllite ground. These features imply that under intense shearing stresses there has occurred in the shales of colliery A.2 a retrogression from some other facies, probably similar to that of the A.1 and A.3 shales, though this is not demonstrable. It may be that this petrological difference between the shales of the anthracite mines is to some extent accountable for the difference in the incidence of pneumokoniosis, but in considering the variations in incidence within the group of anthracite mines, quantitative as well as qualitative considerations must be taken into account. In this connection, it has been shown by Bedford and Warner (p. 59) that the concentration of minerals other than coal in the air-borne dust at colliery A.2 is substantially less than that at collieries A.1 and A.3.

While sharp contrasts in mineralogical and textural detail which appear to be correlated with pneumokoniosis incidence have been described, there are further petrological problems that merit study in relation to the incidence of pulmonary changes in the workers. Some of these are outlined on pp. 143-144.

V.—SUMMARY AND CONCLUSIONS

Samples of material representative of strata exposed at the coalface at six selected collieries in the South Wales coalfield have been subjected to mineralogical and petrological examination. Petrologically, these samples fall into two

contrasted groups : (I) those from three non-anthracite mines (S.4, B.2 and B.3), and (II) those from the anthracite mines A.1, A.2 and A.3.

The basis of the contrast between the two groups is the degree of metamorphism that has been brought about by pressure. The criteria of this metamorphism, which are both textural and mineralogical, are to be sought in the shale substance, for that is highly sensitive to influences concerned in metamorphism. In the shales, pronounced compaction effects become evident, and—due to the increased pressure, and probably also to the influence of higher rock temperatures—the content of secondary quartz and mica increases, and higher grade differentiation effects are achieved in the groundmass. These metamorphic changes run parallel with the rank of coal, the greater changes being evident at the anthracite end of the scale.

In the group of samples from non-anthracite mines (Group I) metamorphism is only incipient. Of the anthracite group (Group II), the samples from collieries A.1 and A.3 show more advanced metamorphism. The samples from colliery A.2 differ from those from the two other anthracite mines. They have many features in common with "fault-gouge" peculiar to phyllite ground, and the general appearance implies that retrogression has been caused by intense shearing stresses. The retrogression is probably from some facies of the A.1 and A.3 status, but this is not demonstrable.

The two groups do not constitute an unbroken sequence of metamorphic grades : the change from the first to the second group is abrupt. But although transitional grades are lacking, there can be little doubt that they could be found by further sampling in this coalfield.

The incidence of pneumokoniosis appears to be positively associated with the geological changes induced by pressure ; it increases as the rank of coal changes from bituminous coal to high-grade anthracite, and our observations show that there is a relationship between the incidence of pulmonary abnormalities in the workers and the degree of metamorphism induced by pressure in the shales. High incidences of radiographical abnormalities are associated with increased compression effects in the shales that form the clods and roofs, with an increase in the content of secondary quartz and mica, and with high-grade differentiation effects in the groundmass. This association stands out clearly in a comparison of anthracite with non-anthracite mines. Within the group of anthracite mines examined, differences in the incidence of pulmonary abnormalities are again related to these compaction effects ; for at the single low incidence mine included in the group there is evidence to suggest that under intense shearing stresses a retrogression from the typical appearance of anthracite shales has occurred.

It cannot at present be proved that the relation between geological changes and the incidence of pneumokoniosis is direct, for it has been shown that the concentration of minerals other than coal in the air-borne dust at the coalface is also correlated with that incidence. It is possible that the differences in concentration of dust in the air are to some extent due to the petrological differences which have been described.

While the mineralogical and petrological differences already considered appear to be directly or indirectly correlated with pneumokoniosis incidence, there are further petrological problems that merit study in relation to the incidence of pulmonary disease.

The first of these concerns the unequal distribution of finely particulate secondary quartz, developed, *pari passu* with sericite progression, in the pulverulent shales and shale substance interstitial to the coarser detrital quartz grains, etc., in clifts and sandstones. In the shale samples from non-anthracite mines that we have examined, the discrimination of secondary quartz nuclei from certain other particulate matter in the groundmass has rarely been certain, but we have provisionally assessed them as "scanty". In the samples from

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the anthracite mines, and especially in those from collieries A.1 and A.3, these quartz nuclei are definite, but in the samples from colliery A.2 the criteria of secondary origin are largely obscured, or even obliterated, by shearing.

The second problem that needs elucidation is the unequal distribution of two important depressants of silica solubility, viz., hydrated ferric oxide and alumina. In our shale samples from the non-anthracite mines hydrated ferric oxide, in the free state, is dispersed throughout the groundmass; but in the samples from the anthracite mines it is very scanty; through metamorphic changes it has given place to the reduced, ferrous, oxide.

With regard to alumina, our observations, so far as they go, suggest that the type of groundmass found in the samples from the non-anthracite group of mines, while poor in particulate secondary quartz and containing free ferric hydroxide, is the richer in per-aluminous mineral substance. It is probably richer in specific terms such as kaolinitic minerals; and also in non-specific substances which are obscurely crystalline and indeterminable, though they are likely to be colloidal substances in which hydrated silica, alumina and ferric oxide, together with alkalis and other bases, are loosely combined; some of these constituents—notably soda—are readily releasable to mild extractive reagents acting selectively. In the groundmass found in the samples from the anthracite mines particulate secondary quartz is evident and has evolved *pari passu* with sericite. This groundmass contains very little free hydrated ferric oxide; the per-aluminous bodies in it are reduced in amount; and the ultimate groundmass residuum is less aluminous, more ferro-magnesian, and more siliceous than its analogue in the material from the non-anthracite mines. The shales from colliery A.2 present a special case.

Outstanding problems concerning the groundmass are less likely to be solved by bulk-analysis than with the aid of analytical technique designed to be delicately selective in its operation.

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SUPPLEMENTARY DATA

TABLE LXVI

Shales from collieries A.3 and A.2. Comparative analyses by Geochemical Laboratories, London, for bulk-samples and air-elutriated fractions (showing that air-elutriated fractions differ little from the bulk-samples)

	Colliery A.3		Colliery A.2	
	Original bulk-sample per cent.	Air-elut. - 2 μ frac. per cent.	Original bulk-sample per cent.	Air-elut. - 2 μ frac. per cent.
SiO ₂	49.18	48.88	49.61	47.80*
Al ₂ O ₃	23.76	24.49*	24.78	25.77*
FeO†	5.23	4.83*	3.60	3.55
MgO	1.57	1.46	1.55	1.67
CaO	0.36	0.33	0.27	0.27
Na ₂ O	0.64	0.81	0.74	0.79
K ₂ O	4.25	4.39	4.15	4.36
Water (+ 105° C.)	7.22	n.d.	7.29	n.d.
Water (- 105° C.)	2.24	n.d.	1.79	n.d.
TiO ₂	0.80	0.77	0.69	0.63
C	1.20	2.18‡	5.98	5.83
CO ₂	3.45	n.d.	n.d.	n.d.
	99.90	88.14	100.45	90.67
Loss on ignition	12.84	12.40	14.80	14.70
Base-exchange capacity	68.1-69.5	58.6	32.9-33.6	34.4
pH	8.3	7.9	8.4	8.0

Not determined : FeO, S, SO₃, MnO, Cl, and F.

* Quantity of sample insufficient for confirmation of figures.

† Calculated on the assumption that all the iron is present in the ferrous condition.

‡ Includes carbon combined as carbon dioxide.

TABLE LXVII
Supplementary analyses of strata, etc.

Sample No. :— (for description see below)	1. per cent.	2. per cent.	3. per cent.	4. per cent.	5. per cent.	6. per cent.	7. per cent.	8. per cent.	9. per cent.	10. per cent.
SiO ₂	65.06	60.42	57.54	57.35	54.15	50.48	48.39	47.89	46.99	61.20
Al ₂ O ₃	20.05	20.79	22.83	25.65	25.86	22.49	19.88	37.32	25.34	19.60
Fe ₂ O ₃	0.38	0.36	0.47	0.47	0.47	nil	0.41	0.47	2.33	1.27
FeO	2.12	3.18	3.71	1.62	2.21	3.74†	—	—	—	4.50
MnO	trace	trace	0.04	0.05	nil	0.05	0.01	<0.005	0.28	0.09
MgO	0.94	1.16	0.91	1.12	1.69	1.75	0.69	0.37	1.42	2.42
CaO	0.62	0.53	0.62	0.45	nil	0.27	0.21	0.40	0.34	1.23
BaO	nil	—	—	0.09	0.15	—	0.05	—	0.07	0.05
Na ₂ O	0.76	0.90	0.97	0.57	1.20	2.39	0.57	3.17	0.66	0.45
K ₂ O	2.75	3.35	3.49	4.10	3.93	2.56	2.47	1.79	3.79	3.62
TiO ₂	0.88	1.04	0.87	0.69	0.75	0.76	0.84	—	0.63	0.34
P ₂ O ₅	0.11	0.12	0.12	0.10	0.06	0.11	nil	—	0.11	0.07
CO ₂	0.63	1.38	2.25	1.26	0.85	0.09	0.17	—	2.89	0.58
SO ₂	—	—	—	nil	—	—	nil	—	nil	0.05
S	0.08	0.08	0.06	0.04	0.20	0.37	0.14	—	0.20	0.37
F	trace	trace	trace	n.d.	0.04	n.d.	n.d.	n.d.	n.d.	n.d.
H ₂ O + 105°	3.01	3.76	2.96	5.55	4.84	7.00	7.20	n.d.	6.19	3.81
H ₂ O - 105°	1.04	1.40	0.95	1.27	1.60	1.29	0.90	n.d.	1.39	0.14
C	1.82	1.46	2.04	n.d.	2.09	7.16	n.d.	—	—	—
Cr ₂ O ₃	—	—	—	—	—	—	—	—	—	0.10
Less O for S	100.25 0.04	99.93 0.04	99.83 0.03	99.91 0.02	100.09 0.02	100.51 0.18	81.93 0.07	91.41 —	92.63 0.10	99.89 0.19
	100.21	99.89	99.80	99.89	100.07	100.33	81.86	91.41	92.53	99.70

- † Figure probably too high owing to the presence of carbon.
1. A.3 (Stanllyd seam) : hard fireclay, F. Analyst : W. H. Herdsman.
 2. A.3 (Stanllyd seam) : strong clift, B. Analyst : W. H. Herdsman.
 3. A.3 : P. Analyst : W. H. Herdsman.
 4. B.3 : roof, 1st rippings. Analysts : Geochemical Laboratories.
 5. A.3 (Stanllyd seam) : clod C. Analyst : W. H. Herdsman.
 6. A.2 : clod. Analysts : Geochemical Laboratories.
 7. B.2 : clod at top of seam. Analysts : Geochemical Laboratories.
 8. A.2 : mica-rich film-and-crust. Analysts : Geochemical Laboratories.
 9. B.3 : clod at top of seam. Analysts : Geochemical Laboratories.
 10. Witwatersrand basket : groundmass. Analysts : Geochemical Laboratories.

TABLE LXVIII

Montmorillonite and beidellite : their variable composition and base-exchange capacity

	Montmorillonite.*				Montmorillonite.	Beidellite.	Beidellite.
	1.	2.	3.	4.	5.†	6.†	7.†
SiO ₂ ..	53.32	52.99	51.90	52.49	51.27	47.08	46.90
Al ₂ O ₃ ..	14.50	14.34	15.52	15.01	23.55	28.92	20.11
Fe ₂ O ₃ ..	5.70	4.63	4.45	4.87	0.45	0.73	8.61
FeO ..	0.89	1.70	0.98	1.38	—	—	—
MgO ..	3.36	3.51	3.85	3.69	2.22	0.17	0.69
CaO ..	2.23	2.81	3.30	2.56	2.03	2.86	2.72
Na ₂ O ..	nil	nil	nil	nil	0.47	0.10	0.96
K ₂ O ..	nil	nil	nil	nil	trace	0.12	trace
H ₂ O ..	20.00	20.00	20.00	20.00	20.00	20.00	20.00
	100.00	99.98	100.00	100.00	99.99	99.98	99.99
B.E. capacity	88	107	122	109	107	120	113

* Brammall, A. & Leech, J. G. C. : Montmorillonite in fuller's earth, Nutfield, Surrey, *Geol. Mag.*, 1940, 77, 102.

† Nagelschmidt, G. : On the atomic arrangement and variability of the members of the montmorillonite group, *Min. Mag.*, 1938, 25, 140.

PLATE E III

Photomicrographs by Geochemical Laboratories, London

Photomicrographs in pairs, showing the same field at magnification $\times 560$ (a) in ordinary light and (b) between crossed nicols.

Group I (p. 136)—Non-anthracite shales :

Figs. A (i) and (ii) : colliery S.4 shale ; section parallel to bedding.

„ B (i) and (ii) : colliery B.2 shale ; section transverse to bedding.

„ C (i) and (ii) : colliery B.3 shale ; section parallel to bedding.

Features seen in ordinary light :

Larger (inset) units in the general groundmass-fabric—a flake-and-fibre plexus riddled with granular to dust-fine mineral and coaly particles, and blackened by larger wisps and patches of coaly matter.

Dispersed “ free ” hydrated ferric oxide also photographs dark-grey to black.

Individual flakes of mica, etc., are only vaguely discernible in the Group I photographs ; but they are distinctly seen in the Group II series (Plate E IV).

Features seen between crossed nicols :

The white patches, grading down to “ pin-point ” size, represent units of the more transparent, more strongly birefringent crystalline minerals.

The smallest “ pin-point ” of white represents merely the smallest grade-size brought into sharp focus by the camera ; the actual sizes range much below this limit, but are merged by the camera into the dark-grey or black area which (after allowance is made for that part of it attributable to coal, etc.) affords an approximate measure of “ actual groundmass ”—composed of a mat of minute “ dusty ” flakes and fibres of feebly birefringent (to essentially isotropic) mineral matter.

Seriate growth is well illustrated by the colliery B.3 section : an apparently single mica-flake seen in the upper right-hand corner of the field is resolved between crossed nicols into a colony of flakes in different stages of development from “ ultimate groundmass ” (nearly isotropic between crossed nicols).

Seriate growths are barely discernible in the colliery S.4 shale ; they are clearer in the colliery B.2 shale and well illustrated by the B.3 shale.

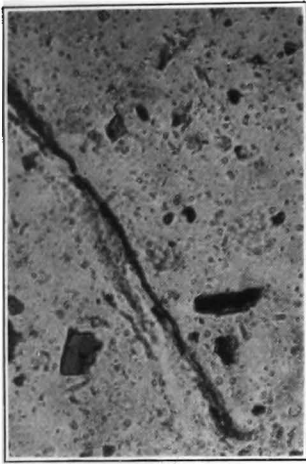


FIG. A (i)

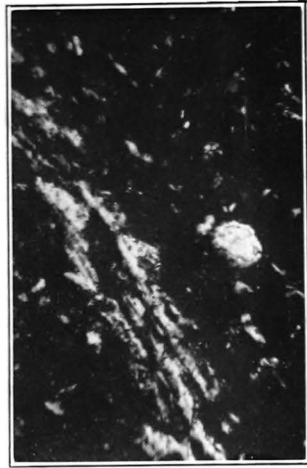


FIG. A (ii)

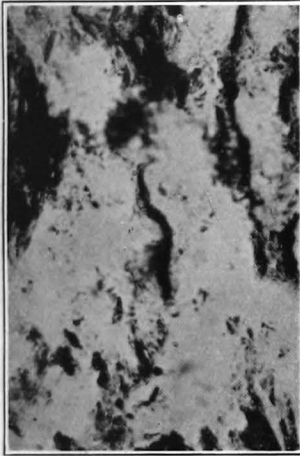


FIG. B (i)

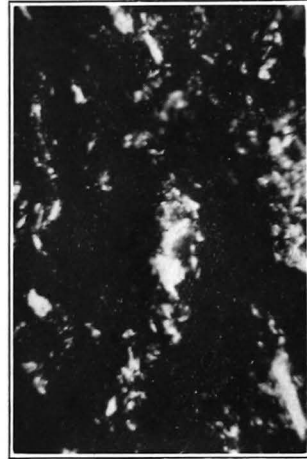


FIG. B (ii)

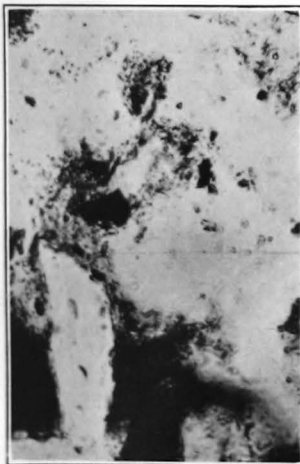


FIG. C (i)

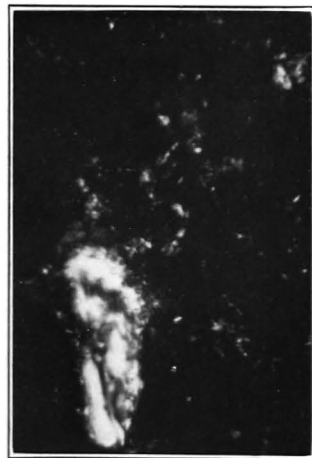


FIG. C (ii)

PLATE E IV



FIG. A (i)



FIG. A (ii)

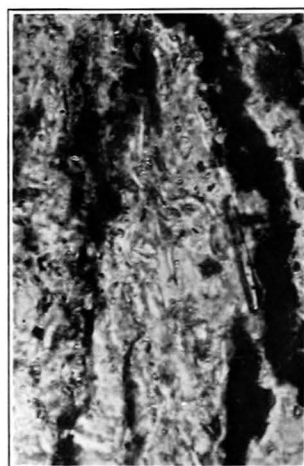


FIG. B (i)



FIG. B (ii)

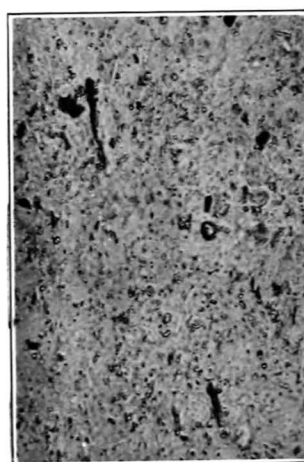


FIG. C (i)

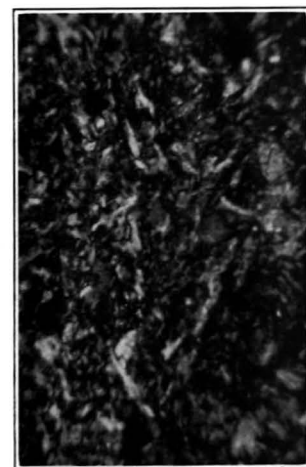


FIG. C (ii)

PLATE E IV

Photomicrographs by Geochemical Laboratories, London

Photomicrographs in pairs, showing the same field at magnification $\times 560$ (a) in ordinary light and (b) between crossed nicols.

Group II (p. 136)—Anthracite shales :

Figs. A (i) and (ii) : colliery A.2 shale ; section transverse to shear-planes.

„ B (i) and (ii) : colliery A.1 shale ; section transverse to bedding.

„ c (i) and (ii) : colliery A.3 shale ; section transverse to bedding.

Features seen in ordinary light :

Larger (inset) units in the general groundmass-fabric—a flake-and-fibre plexus riddled with granular to dust-fine mineral and coaly particles, and blackened by larger wisps and patches of coaly matter.

Dispersed “ free ” hydrated ferric oxide also photographs dark-grey to black.

Individual flakes of mica, etc., are distinctly seen in the Group II series.

Minute prisms of rutile are best developed in the colliery A.3 shale.

Parallelism due to shearing (colliery A.2) is more pronounced than parallelism conformable to bedding.

Features seen between crossed nicols :

The white patches, grading down to “ pin-point ” size, represent units of the more transparent, more strongly birefringent crystalline minerals.

The smallest “ pin-point ” of white represents merely the smallest grade-size brought into sharp focus by the camera ; the actual sizes range much below this limit, but are merged by the camera into the dark-grey or black area which (after allowance is made for that part of it attributable to coal, etc.) affords an approximate measure of “ actual groundmass ”—composed of a mat of minute “ dusty ” flakes and fibres of feebly birefringent (to essentially isotropic) mineral matter.

Seriate growth is general in these anthracite shales.

PLATE E V

Photographed from scaled drawings

- Fig. A. *Upper part* : ($\times 10$). A transverse section of colliery A.3 "strong clift" —highly quartzose, with interstitial shale-substance. (Ordinary light.)
Lower part : ($\times 140$). Interstitial shale-substance viewed at high magnification and between crossed nicols; showing quartz (both primary and secondary), and seriate mica-growths—inset in groundmass plexus giving "aggregate polarisation" colours (low-order grey and dark-grey registered by the camera as "black").
- Fig. B. ($\times 19$). Minute lenses of mineral matter in a band of anthracite, colliery A.3. (Between crossed nicols.)
Identifiable minerals include kaolin, mica, pyrite, carbonate, and (rarely) quartz.
- Fig. C. ($\times 140$). Mineral matter in "bord coal", colliery A.3. Mineral assemblage similar to that listed under Fig. B. (Between crossed nicols.)
- Fig. D. *Upper part* : ($\times 11$). Lenses of mineral matter in anthracite, colliery A.3. (Crossed nicols.)
Lower part : ($\times 150$). A minute lens ground to extreme thinness (the medial portion is partly rubbed away); displaying the flake-and-fibre plexus composed largely of kaolin and mica; quartz is rarely coarse enough to be identifiable with certainty. (Crossed nicols.)

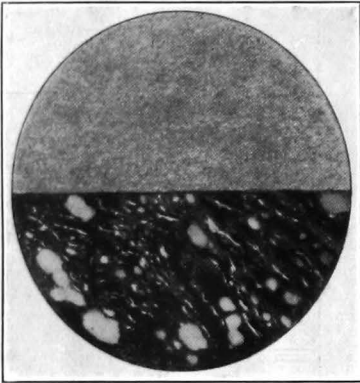


FIG. A

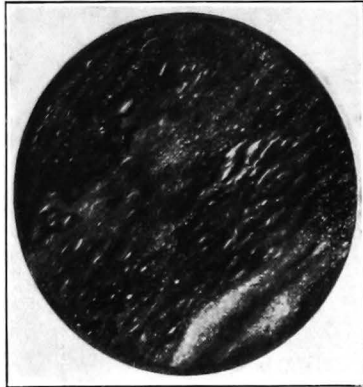


FIG. B

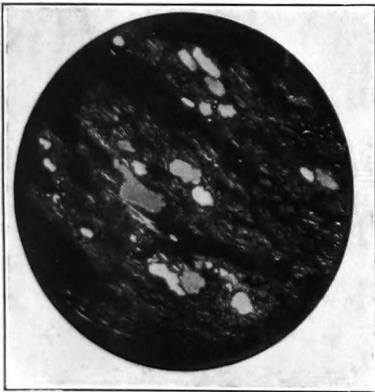


FIG. C

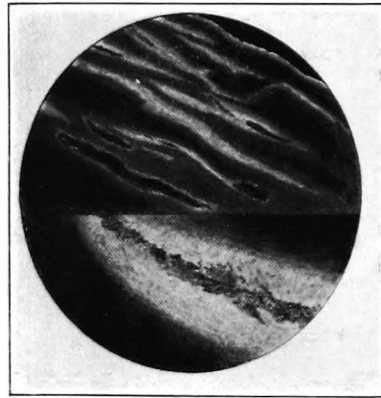


FIG. D

PLATE E VI

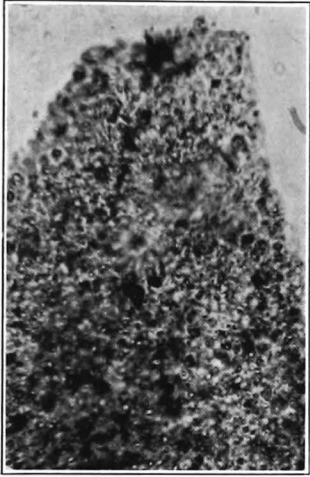


FIG. A

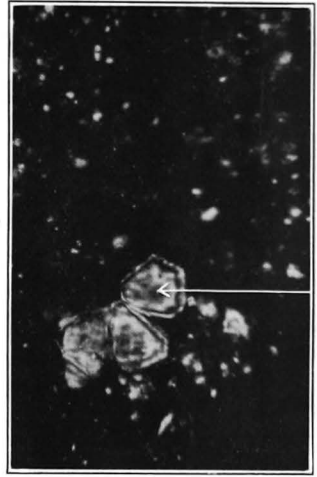


FIG. B

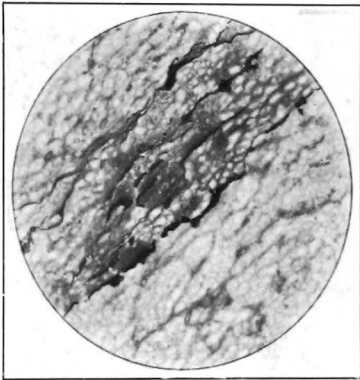


FIG. C

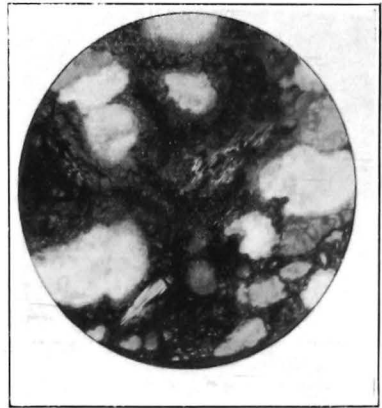


FIG. D

PLATE E VI

Photomicrographs, at magnification $\times 560$, by Geochemical Laboratories, London

Fig. A. A typical "micaceous flakes" from a colliery B.3 "fine fraction"—seen in ordinary light. The flake is riddled with inclusions.

Fig. B. The same flake (same field) examined between crossed nicols, with focus adjusted so that the "fuzzy area" near the middle of the field in Fig. A is resolved into a triad of dickite-like flakes (indicated by an arrow). Lack of homogeneity in the host-mineral (mica) is again apparent from the number of birefringent particles still in focus.

Photographed from scaled drawings in colour

Fig. C. ($\times 19$). A transverse section of the highly compressed colliery A.3 "strong clift" (quartzose), viewed in ordinary light.

Showing abundant quartz, dispersed coaly matter, and interstitial coaly shale-substance.

The quartz units show an appreciable tendency to assume a lenticular outline, due in part to the precipitation of "secondary quartz" in clustered nuclei along planes at right-angles to compression. These clusters gradually integrate to homogeneous plates—often in optical continuity with a large near-by quartz unit (primary or secondary). Note the two cases of "integration" in progress near the margin of Fig. D—at about N. 45° E. and N. 120° E.

Fig. D. ($\times 140$). A quartzose field in the interstitial groundmass-substance of the colliery A.3 "strong clift": showing the integration of secondary-quartz clusters (Fig. C), secondary mica (e.g. a skeletal growth near the centre of the field), and a well-integrated and now robust mica unit near the S.W. margin of the field.

The ultimate groundmass is the usual plexus—rich in finely-divided flake-and-fibre units with some secondary quartz.

PLATE E VII

Scaled drawings

(At magnifications $\times 1,000$ to $\times 1,400$)

Fig. 1. Typical particles in a water-elutriated "fine fraction" of the colliery A.1 shale.

- Showing (a) "partitioning", due to nuclear re-crystallisation ;
(b) dust-fine inclusions, notably short, stumpy prisms of rutile ;
particulate carbonate, and coaly matter ;
(c) *superficial* pigmentation by hydrated ferric oxide—a
"weathering" effect produced by the oxidation and hydration
of a Fe²⁺-bearing groundmass-silicate either during water-
elutriation or by exposure to air.

Fig. 2. A micaceous "fine fraction" obtained by water-elutriation from a colliery B.3 shale ; similarly pigmented by hydrated ferric oxide.

Fig. 3. An air-elutriated "fine fraction" of the colliery B.3 shale—made up of composite particles (Fig. 4).

Fig. 4. The field shown in Fig. 3, but viewed between crossed nicols. Few of the "pin-points" of high light in these composite flakes are determinable, microscopically at least, as quartz.

Small insert circle: A pair of dust-particles from a colliery A.1 shale, viewed between crossed nicols. The composite flakes contain nuclei of secondary quartz showing the characteristic growth-habit.

Fig. 5. A section of colliery B.2 shale parallel to bedding.

- Showing (a) minute coccoliths of partly oxidized and hydrated siderite, and
(b) relatively clear polygonal outlines of flakes having a dickite-
like character.

These are the main determinable insets in the groundmass plexus.

Fig. 6. A section of colliery B.3 shale transverse to bedding ; showing the microstructure of one of the siderite bands (0.0055 in. thick) illustrated by Plate E II, Fig. A.

PLATE E VII.

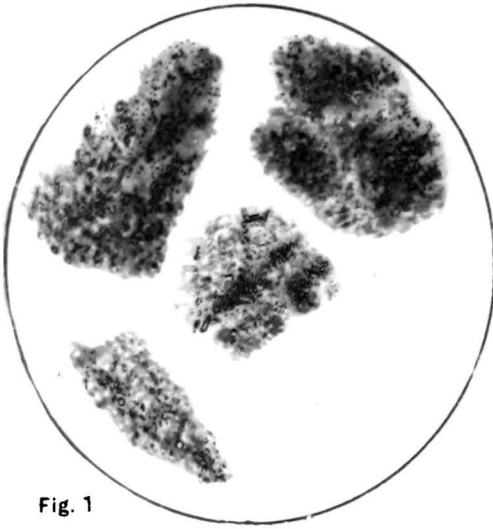


Fig. 1

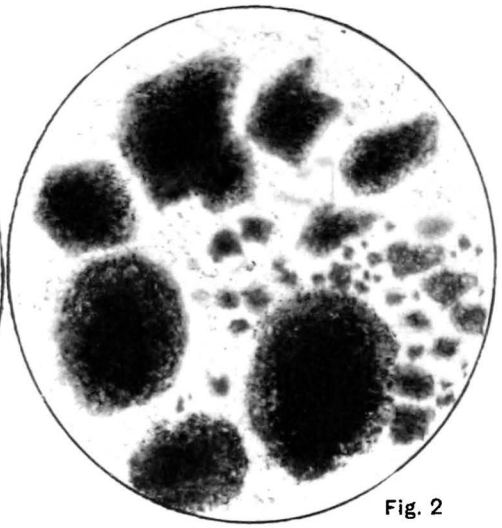


Fig. 2

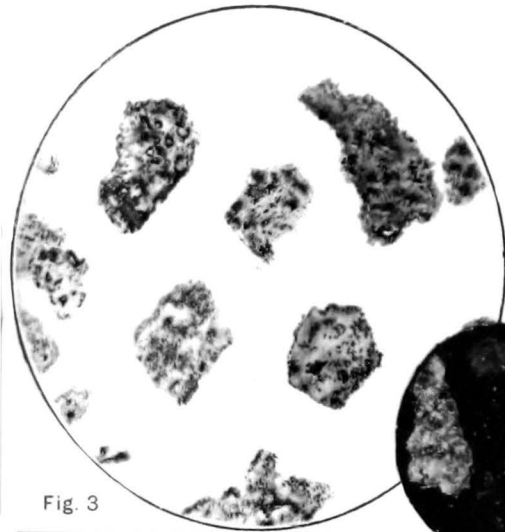


Fig. 3

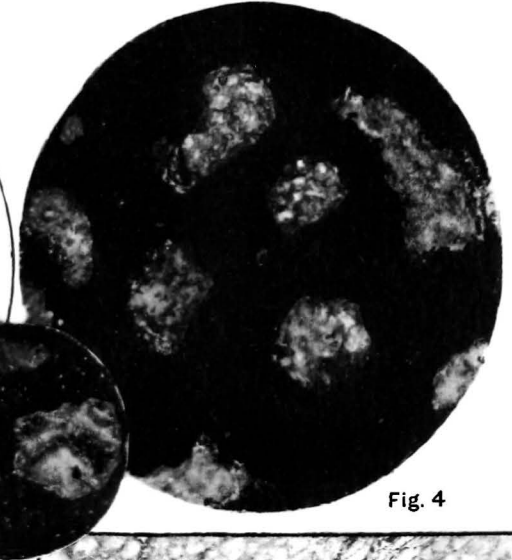


Fig. 4

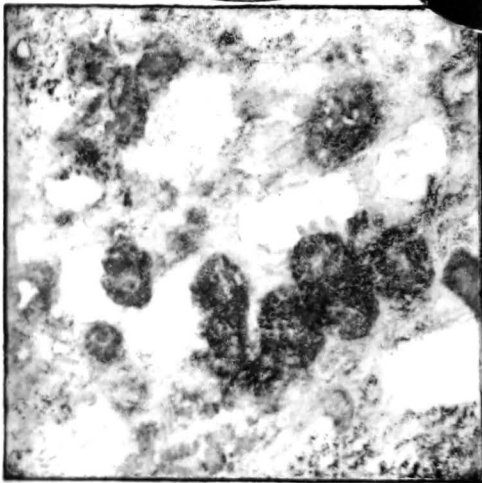


Fig. 5

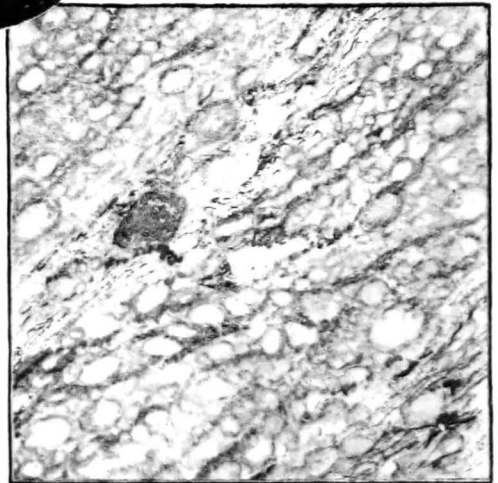


Fig. 6

CHRONIC PULMONARY DISEASE IN SOUTH WALES COAL-MINERS. II.—ENVIRONMENTAL STUDIES

F.—THE CHEMICAL AND X-RAY DIFFRACTION ANALYSIS OF THE ROOF AND CLOD OF SOME SOUTH WALES SEAMS, AND OF THE MINERAL MATTER IN THE COAL

BY

D. HICKS, M.Sc., A.I.C.

(Officer-in-Charge, Coal Survey Laboratory, Cardiff)

AND

G. NAGELSCHMIDT, D.Phil.

(Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts)

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INTRODUCTION

It has been stressed in the report on the medical survey, and in the pathological report, that dust is probably the most important factor in the causation of the pneumokoniosis of coalminers. The concentration and composition of the air-borne dust at the coalface have been discussed in other parts of this symposium, and the present section deals with the nature of the sources of the dust, i.e., the coal seam and the shale strata immediately above the seam, with which the collier comes into contact in the course of his work. A description of the general structure of the seams in South Wales is given in the report on the

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medical survey (*Spec. Rep. Ser. Med. Res. Coun., Lond., No. 243, 1942, pp. 18-20*) and from this, and from the account given of the various methods of mining, it will be seen that, in addition to the coal, the collier handles a considerable amount of clod and roof.

A coalseam is not a single homogeneous bed of coal, of uniform thickness throughout the coalfield. The thickness often varies appreciably from place to place, and the general sections of the many workable seams differ considerably from each other. It is therefore impossible to present a simple picture of the South Wales seams. Nevertheless, they have many common features, which are illustrated in Fig. 14, a diagrammatic section of a seam consisting of two main beds of coal.

The floors of the seams are usually beds of fireclay, but this does not mean that they are proved refractory clays. Between the floor and the main bed of coal there is often found a thin layer of "rashes", a term used to describe a carbonaceous shale which breaks up easily into small pieces with smooth slickensided surfaces. The term "roof" may be defined as the bed of rock above the seam; this rock is usually a shale in the mines examined, but in some localities it may be a sandy shale or even a sandstone. Between the roof and the top of the coalseam there is often a layer of clod, which may be a hard mudstone or shale.

The seam may consist of one bed of coal; often it consists of two, sometimes of three and occasionally of four or more. These different beds of coal are usually separated by thin layers of rashes, clod or mixtures of clod, rashes and coal. The thickness of these intermediate beds varies very considerably. Usually they are only a few inches thick, but sometimes they are a foot or more, and in some areas these intermediate layers of clod and rashes increase in thickness to such an extent that the main beds of coal become separate workable seams. When the thickness is but a few inches, the two or more beds of coal are mined together and the intermediate layers of clod and rashes are thrown into the gob.

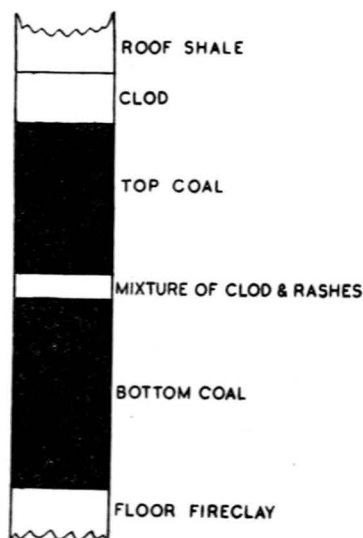


FIG. 14. Diagrammatic section of S. Wales seam consisting of two main beds of coal.

The extent to which the rocks referred to above are mined and handled by the collier depends on a number of factors, which, in turn, depend on the method of mining. In South Wales the floors of the seams are not often lifted, except

in some instances when roads are being repaired, and in steeply inclined seams when the tophole system of working is adopted; in the latter case, the floors of the seams are excavated in the levels, to make room for the trams to be pushed under the loading chutes from the topholes. Occasionally, when the roof is a hard sandy shale, it is not disturbed and the necessary height in the roadways is obtained by excavating the floor. The clod at the top of the seam is usually brought down along the whole length of the face. The extent to which the roof is mined depends on the thickness of the seam and on the method of mining. Usually only sufficient is brought down in the roadways to give the necessary height for the traffic. In the thinner seams a few feet of roof strata have to be excavated in the roadways as the face advances, but in the thicker seams it is usually only necessary to bring down a little of the roof when repairing the roadways, and then only sufficient to maintain the necessary height.

It will thus be evident that, in addition to the coal, the collier may handle quite considerable quantities of the closely associated strata.

The air-borne dust is a complex mixture, which consists of the coal substance itself, mineral matter in the seam, dust from the overlying clod and roof and from the mining of intermediate bands of clod, rashes and carbonaceous shale in the seam. Any differences in the composition of the various dusts cannot be interpreted without reference to their sources. The composition and concentration of the dusts vary also from time to time and may partly depend on the particular operations in progress. When a collier is ripping and handling roof or clod, the major part of the air-borne dust formed from the breaking of these strata will approximate to their composition; thus, a study of the sources of the dust, in addition to providing data to interpret the composition of average samples of air-borne dust, also indicates the probable variation in the composition of the dust found during various working operations (see report by Briscoe *et al.*, p. 84, "C" and "M" samples).

The most striking finding of the medical inquiry is the relation between the incidence of pulmonary X-ray abnormalities and the rank of the coal mined; the higher the rank, the higher the incidence, although there are also contrasts within the anthracite area. This relation might be due to differences in the rocks, in the mineral matter of the coalseam or in the coal substance itself. The present report gives the results of chemical and X-ray diffraction analyses of representative samples of roof and clod, and of the mineral matter in the seams. Petrological descriptions of some of the same roof and clod samples, and additional chemical data, have been given in the report by Brammall and Leech.

Nine roof samples, and ten samples of clod overlying the seams, have been examined from eight of the sixteen collieries covered by the medical survey. They include, as shown in Table LXIX, high and low-incidence anthracite and low-incidence non-anthracite mines. As in the report on the medical survey, the code letters "A", "S", and "B" are used to indicate anthracite, steam coal (carbonaceous and semibituminous) and bituminous coal, respectively. The terms "high-" and "low-incidence mines" represent mines at which the medical survey revealed a high and low incidence of pulmonary X-ray abnormalities amongst the colliers (see *Spec. Rep. Ser. No. 243*, p. 72). Mines A.1 and A.2 were selected because the same seam, the Lower Pumpquart, is worked at both of them, but A.1 is a high-incidence and A.2 a low-incidence mine. Similarly, the Red Vein is worked at A.5 (low-incidence) and A.6 (high-incidence). The selection of mines thus embraces the general contrast between anthracite and bituminous collieries, as well as the contrast between high and low-incidence mines within the anthracite area.

The mineral matter in seam pillar samples taken at 18 collieries has been analysed. These include 12 of the 16 collieries covered by the medical survey, one additional anthracite colliery (A.9) with a high incidence of certified silicosis,

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one bituminous colliery (B.6), where the incidence of certified silicosis is high, and four additional bituminous collieries (B.4, B.5, B.7, and B.8) where the incidence of certified silicosis is low. The colliery B.6 is peculiar in this selection; here the Red Ash seam, which is at the base of the Pennant Series, is mined, and the roof is a sandstone. At the other collieries selected the seams mined are in the Lower Coal Series, where the roofs above the seams examined are usually argillaceous shales.

TABLE LXIX
Description of roof and clod samples

<i>Rank of coal.</i>	<i>Incidence of pneumo- hionosis</i>	<i>Colliery.</i>	<i>Seam.</i>	<i>Samples examined.</i>
Anthracite ..	High	A.1	Lower Pumpquart	Roof 37 in., clod 4 in.
Anthracite ..	Low	A.2	Lower Pumpquart	Roof 42 in., clod 6 in.
Anthracite ..	High	A.3 Dist. 1	Stanlyd	Roof 24 in., clod 26 in.
Anthracite ..			A.3 Dist. 2	Stanlyd	Clod 8 in.
Anthracite ..	Low	A.5 Dist. 1	Red Vein	Roof 40 in., clod 12 in.
Anthracite ..			A.5 Dist. 2	Red Vein	Roof 41 in., clod 7 in.
Anthracite ..	High	A.6	Red Vein	Roof 35 in., clod 8 in.
Semi-bituminous	Low	S.4	Two Feet Nine	Roof 12 in., bast or clod 8 in.
Bituminous ..	Low	B.2	Black Vein	Roof 31 in., clod 4 in.
Bituminous ..	Low	B.3	Black Vein	Roof 21 in., clod 11 in.

TABLE LXX
Description of seam samples

<i>Rank of coal.</i>	<i>Incidence of pneumo- hionosis.</i>	<i>Colliery.</i>	<i>Seam.</i>	<i>Thickness of coal, inches.</i>	<i>Volatile matter less CO₂ in dry ash-free coal.</i>	<i>C : H ratio of coal substance</i>
Anthracite ..	High	A.1	Lower Pumpquart	43	4.9	34.0
Anthracite ..	Low	A.2	Lower Pumpquart	36	5.4	31.5
Anthracite ..	High	A.3	Stanlyd	71	6.4	30.0
Anthracite ..	Low	A.5	Red Vein	54	6.7	27.0
Anthracite ..	High	A.6	Red Vein	33	7.4	26.0
Anthracite ..	Medium	A.7	Nine Feet	114	7.8	26.0
Anthracite ..	Medium	A.8	Nine Feet	95	9.5	23.0
Anthracite ..	High*	A.9	Stanlyd	32	5.0	32.0
Carbonaceous ..	Medium	S.3	Nine Feet	94	15.4	21.5
Semi-bituminous	Low	S.4	Two Feet Nine	59	20.1	19.5
Bituminous ..	Low/ Medium	B.1	Rhas Las	60	25.6	18.0
Bituminous ..	Low	B.2	Black Vein	120	27.4	18.0
Bituminous ..	Low	B.3	Black Vein	76	32.6	17.0
Bituminous ..	Low*	B.4	Five Feet	49	31.3	16.5
Bituminous ..	Low*	B.5	Black Vein	71	35.3	16.5
Bituminous ..	High*	B.6	Red Ash	27	32.4	16.5
Bituminous ..	Low*	B.7	Black Vein	94	36.1	16.0
Bituminous ..	Low*	B.8	Black Vein	86	35.2	16.5

* Not included in the Medical Survey. The incidences quoted are those of certified silicosis.

Stanlyd, Nine Feet, Rhas Las, and Black Vein are different local names for the same seam.

The samples form a representative selection of the range of South Wales coals, as can be seen from Table LXX, which gives the names of the seams, the volatile matter less CO₂ in the dry ash-free coals, and the carbon : hydrogen

ratios. Eleven of the samples are from the Nine Feet seam or its correlatives, the Black Vein, Rhas Las and Stanlyd, as this seam has been prominent in the occupational histories of the men examined in the medical survey.

METHODS OF ANALYSIS

All the samples were ignited at 800° C. to constant weight, and the ignited residues analysed chemically. The methods used are those described in Fuel Research Survey Paper No. 50 (in the press) "Improved Methods for the Quantitative Analysis of Coal Ash and Coke Ash". They are based on the normal methods of silicate rock analysis, and were selected for the particular combination of elements found in coal ash and in coal measure shales. During the period of mixing, grinding and preparation for analysis, the ash absorbs some water and carbon dioxide, so that it has been necessary also to determine the loss on ignition at 800° C.

The X-ray diffraction analyses were carried out on the original samples of the roofs and clods, and for the coal samples on residues from igniting them to a constant weight at a temperature of 380° C. Powder and aggregate techniques (Nagelschmidt 1934, 1941) were used in order to identify the minerals and to obtain a rough estimate of their relative amounts. For many of the samples of mineral matter from coal seams, diagrams were taken before and after treating the 380° C. residues with *N* hydrochloric acid.

ROOFS AND CLODS

It is convenient to separate the descriptions and analyses of the roofs and clods, which are, in general, rock samples and show a small loss on ignition, from the description of the coalseam mineral matter samples, which are obtained from coal fractions and consequently have a high loss on ignition. A few samples of floors have been analysed, but, in view of the fact that the floors in South Wales coalmines are usually not mined, their description will be omitted, and this section deals with the roofs and clods which have been analysed.

(A) Roofs

Usually the roof strata are fine-grained argillaceous shales and are referred to locally as clift. Frequently, however, the physical and chemical properties of the shales change as the seam is traced from one locality to another; they sometimes become more arenaceous, and in isolated areas they are almost sandstones. In addition to these lateral changes, there are changes vertically in the nature of the shales overlying the coal seams, but the samples described in this report are average samples of the full thicknesses of the roof shales exposed at normal working places.

(1) Chemical Analyses

The analyses of nine roof shales are given in Table LXXI. Two samples of roof from colliery A.5 were analysed, because in District 2 of this colliery the roof was much harder and more arenaceous than in the other districts. At all the other collieries the nature of the roof above the seams in question appeared to be similar in all the normal working places.

It will be seen from Table LXXI that two of the samples are notably different from the others, namely the roof at colliery A.1 and the roof in District 2 of colliery A.5. The analyses of both these samples are very similar, in that they show a high percentage of SiO_2 (70.69 and 70.03 per cent., respectively), and a low percentage of Al_2O_3 (15.38 and 15.63 per cent.). The percentages of SiO_2 and Al_2O_3 in the other seven samples are similar, and there is no important contrast between the analyses of the samples of roof from the collieries where

TABLE LXXI
Analyses of roofs

Colliery :	A.1.	A.2.	A.3.	A.6.		A.6.	S.6.	B.2.	B.3.
				Dist. 1.	Dist. 2.				
Residue at 800° C.—per cent. air-dried sample ..	93.05	92.28	91.21	90.07	93.99	91.11	88.77	90.87	90.69
CO ₂ —per cent. air-dried sample	3.46	2.09	3.82	3.38	2.79	2.55	4.60	3.46	2.83
Per cent. of residue :—									
SiO ₂	70.69	56.77	63.47	59.79	70.03	60.69	56.27	61.59	60.54
TiO ₂	0.88	0.88	1.06	1.08	0.92	0.93	0.94	1.02	0.98
Al ₂ O ₃	15.38	24.71	20.70	22.00	15.63	22.47	25.15	22.90	24.43
Fe ₂ O ₃	6.01	7.58	7.71	7.68	6.46	8.06	8.48	6.24	6.01
CaO	1.37	0.07	0.10	0.57	0.47	0.43	0.14	0.07	0.07
BaO	0.03	Nil	Nil	0.01	0.01	Nil	Nil	0.09	Nil
MgO	1.59	1.99	1.60	2.00	1.40	1.95	1.50	1.66	1.58
K ₂ O	2.20	4.29	3.21	3.54	2.42	3.17	4.38	3.75	4.19
Na ₂ O	1.10	0.99	0.77	0.51	0.79	1.02	0.62	0.42	0.49
SO ₂	0.06	0.33	Trace	0.75	0.19	0.02	0.19	0.15	0.10
P ₂ O ₅	0.19	0.19	0.16	0.24	0.20	0.19	0.26	0.18	0.15
Loss on ignition at 800° C.	0.27	1.86	0.55	1.82	1.29	0.55	1.33	1.52	1.16
Total	99.77	99.66	99.33	99.99	99.81	99.48	99.62	99.59	99.70
Mols K ₂ O : Mols Na ₂ O	1.32	2.85	2.74	4.57	2.01	2.05	4.65	5.89	5.63

the seams are bituminous and those from the collieries where the seams are anthracite ; the analyses of these seven samples are summarised below.

	Per cent. of 800° C. residue	
	Range	Mean
SiO ₂	56.27-63.47	59.87
TiO ₂	0.88-1.08	0.98
Al ₂ O ₃	20.70-25.15	23.19
Fe ₂ O ₃	6.01-8.84	7.45
CaO	0.07-0.57	0.21
BaO	Nil-0.09	0.01
MgO	1.50-2.00	1.75
K ₂ O	3.17-4.38	3.79
Na ₂ O	0.42-1.02	0.69
SO ₂	Trace-0.75	0.20
P ₂ O ₅	0.15-0.26	0.19
Loss on ignition at 800° C. ..	0.55-1.86	1.26

(2) X-ray Diffraction Analyses

The results of the X-ray diffraction analyses of five of the roof samples are shown in the lower part of Table LXXVIII. Quartz and mica were found in all of them as main constituents, besides some kaolin and carbonates. Throughout this report the term "kaolin" refers to a mineral of the kaolin group and "mica" to a mineral of the mica group. Kaolinite and halloysite are both members of the kaolin group. A powder camera of small radius was used, and most of the diffraction lines of kaolin coincided with mica lines. Aggregate diagrams showed weak lines corresponding to the basal reflexions of kaolin at 7.1 and 3.55A. These lines were absent if the samples had been previously heated to 500° C. The kaolin group contains several minerals which can be distinguished in pure specimens, but there was not enough kaolin in any of the roof samples to make such an identification possible. The estimates "strong", "medium", and "weak" in Table LXXVIII are based on visual comparison of the relative intensities of the diffraction lines of the different minerals. The carbonate proved to be chalybite-FeCO₃, calcite-CaCO₃, ankerite-(Ca,Mg,Fe)CO₃ or dolomite-(Ca,Mg)CO₃. These last two minerals cannot be distinguished from each other on powder diagrams, but they can be distinguished from calcite and chalybite.

(B) Clods

The clods are hard mudstones or shales, sometimes containing thin layers of coal. The thickness of the clod overlying the seam often varies considerably even in the same working district ; thus, in some places it may be 2 to 3 in. thick, whereas in others it may be 1 ft. or more in thickness. It is usually a well-defined layer, distinct from the cliff roof, but at some collieries the term clod is used to describe the thin layers of shale immediately above the seam, which can be brought down easily with the pick.

(1) Chemical Analyses

The analyses of 10 samples of clod are given in Table LXXII. The yields of the residues after incineration at 800° C. are less than those from the samples of the roof. The difference is explained by the fact that the clods contain some coaly matter, especially the sample from colliery S.4, which gave a residue of only 33.7 per cent. at 800° C. This sample is not a normal clod, but an intimate mixture of coal and clod, referred to locally as "bast".

The percentage of SiO₂ in the ash of the clod samples varies between 52.46 and 64.21, and that of Al₂O₃ between 20.10 and 31.81. The percentages of SiO₂ and Al₂O₃ in the samples from collieries A.1, A.5 and B.2 are very

TABLE LXXII

Analyses of clods

Colliery :	A.1.	A.2.	A.3.		A.5.		A.6.	S.4.	B.2.	B.3.
			Dist. 1.	Dist. 2.	Dist. 1.	Dist. 2.				
Residue at 800° C.—per cent. air-dried sample	90.40	87.52	84.5	93.6	89.74	91.94	51.53	33.68	62.35	78.99
CO ₂ —per cent. air-dried sample	0.09	1.28	0.42	1.87	2.63	1.42	0.20	0.37	0.46	2.17
<i>Per cent. of residue :—</i>										
SiO ₂	62.91	55.82	56.40	58.30	61.34	62.19	52.46	59.06	64.21	56.18
TiO ₂	1.14	0.82	0.68	0.46	1.08	1.04	0.80	0.86	1.08	0.86
Al ₂ O ₃	23.30	26.83	31.01	27.45	20.10	21.97	31.81	30.26	26.56	28.50
Fe ₂ O ₃	4.32	5.93	2.77	4.53	8.29	6.27	5.11	1.95	1.84	5.44
CaO	Nil	0.07	0.17	0.13	0.46	0.22	0.34	0.15	0.22	0.18
BaO	Trace	Nil	0.10	0.33	0.01	Nil	Nil	0.01	Nil	Nil
MgO	1.67	1.95	1.42	1.34	1.77	1.70	1.59	1.30	1.15	1.74
K ₂ O	4.10	4.72	5.40	4.52	3.24	3.91	4.19	5.28	3.47	5.17
Na ₂ O	1.17	0.98	0.95	0.92	0.52	0.49	0.92	0.33	0.43	0.52
SO ₂	0.06	0.34	0.04	0.10	1.21	0.43	0.16	0.31	0.33	0.21
P ₂ O ₅	0.13	0.16	0.24	0.21	0.24	0.18	0.14	0.16	0.19	0.24
Loss on ignition at 800° C.	1.03	2.45	N.D.	N.D.	1.53	1.74	0.86	0.70	0.50	0.58
Total	99.83	100.07	99.18	98.29	99.79	100.14	98.38	100.37	99.98	99.62
Mols K ₂ O : Mols Na ₂ O	2.30	3.17	3.74	3.23	4.10	5.25	2.99	10.53	5.31	6.54

similar; they contain more SiO₂ and less Al₂O₃ than do the others. The analyses of the remaining six samples can be summarised as follows:—

	Per cent. of 800° C. residue	
	Range	Mean
SiO ₂	52.46-59.06	56.37
TiO ₂	0.46- 0.86	0.75
Al ₂ O ₃	26.83-31.80	29.47
Fe ₂ O ₃	1.95- 5.93	4.29
CaO	0.07- 0.34	0.17
BaO	Nil- 0.33	0.07
MgO	1.30- 1.95	1.56
K ₂ O	4.19- 5.40	4.88
Na ₂ O	0.33- 0.98	0.77
SO ₃	0.04- 0.34	0.19
P ₂ O ₅	0.14- 0.24	0.19
Loss on ignition	0.58- 2.45	1.15

Comparing these data with the summary of the roof samples, it will be seen that, in the main, the 800° C. residues from the clods contain higher percentages of Al₂O₃ and K₂O and a little less SiO₂ and Fe₂O₃ than the 800° C. residues from the roof shales.

(2) X-ray Diffraction Analyses

The data, in the lower part of Table LXXIX, are similar to those for the roofs and show that the main constituents are mica and quartz, with kaolin and sometimes carbonates as minor constituents.

(C) Fine Fractions

The samples of roof and clod are mixtures of several minerals, and in order to calculate their quantitative composition from the analyses given in Tables LXXI and LXXII, it is necessary to know the chemical composition of the various constituents. An attempt was therefore made to isolate the mica from the roofs or clods by grain-size separations. Fractions of about 0.5 micron equivalent diameter, referred to below as "fine fractions," were prepared from five of the clod and one of the roof samples, by repeated sedimentation in water, followed by ultrafiltration of the suspensions obtained.

TABLE LXXIII
Analyses of air-dried fine fractions

Colliery :	A.1.	A.2.	A.3.		S.4.	B.3.
			Dist. 1.	Dist. 2.		
Per cent. air-dried sample :						
SiO ₂	44.64	44.16	46.65	47.43	46.08	45.94
TiO ₂	0.56	0.50	0.51	0.44	0.61	0.59
Al ₂ O ₃	31.52	31.01	31.39	32.97	30.97	30.38
Fe ₂ O ₃	3.30	3.24	1.63	1.33	2.71	1.58
CaO	Nil	0.08	0.05	Nil	Nil	0.17
MgO	1.73	1.69	1.24	1.37	1.33	1.26
K ₂ O	5.22	5.34	5.12	5.23	5.34	5.22
Na ₂ O	1.22	0.87	1.05	1.08	0.62	0.50
H ₂ O - 105° C. ..	3.25	3.03	3.13	3.00	3.25	2.89
H ₂ O + 105° C. ..	8.41	8.36	7.28	7.76	7.61	8.16
CO ₂	0.06	0.14	N.D.	N.D.	N.D.	N.D.
Total	99.91	98.42	98.05	100.61	98.52	96.69
Mols SiO ₂ : Mols Al ₂ O ₃	2.40	2.42	2.52	2.44	2.52	2.57
Mols K ₂ O : Mols Na ₂ O	2.82	4.04	3.21	3.18	5.67	6.87

All the samples, with the exception of S.4, were prepared from clods; the fine fraction from S.4. was prepared from a sample of roof.

(1) *Chemical Analyses*

The chemical analyses of the air-dried fine fractions are given in Table LXXIII. It will be seen that, with the exception of the percentage of Na_2O , these samples are very similar whether they are isolated from the rocks above the anthracite or above the bituminous seams. The $\text{SiO}_2 : \text{Al}_2\text{O}_3$ ratios vary only between 2.40 and 2.57, but there is a marked difference in the $\text{K}_2\text{O} : \text{Na}_2\text{O}$ ratios of the fine fractions separated from the samples from the semi-bituminous and bituminous coal collieries and those from the anthracite collieries. The fine fraction from the clod from the high rank anthracite at A.1 has a $\text{K}_2\text{O} : \text{Na}_2\text{O}$ ratio of 2.82, and that from the clod from above the lower rank bituminous coal at B.3 is 6.87. The $\text{K}_2\text{O} : \text{Na}_2\text{O}$ ratios of the fine fractions, roofs and clods, given in Table LXXIV, all show the same effect—i.e., an increase with decreasing rank of the coal.

TABLE LXXIV
The molar ratio of $\text{K}_2\text{O} : \text{Na}_2\text{O}$ in fine fractions, clods and roofs

Colliery.	A.1.	A.2.	A.3.		S.4.	B.3.
			District 1.	District 2.		
Fine fraction	2.82	4.04	3.21	3.18	5.67*	6.87
Clod	2.30	3.17	3.74	3.23	10.53	6.54
Roof	1.32	2.85	2.74	—	4.65	5.63

* Isolated from roof.

TABLE LXXV
*Water loss determination of air-dried fine fractions
Per cent. air-dried sample*

Colliery :	A.1.	A.2.	A.3.		S.4.	B.3.
			Dist. 1.	Dist. 2.		
Temperature, °C. :						
105	3.25	3.03	3.13	3.00	3.25	2.89
200	5.02	4.35	4.25	4.28	4.87	3.71
300	5.78	5.13	4.80	N.D.	N.D.	4.25
440	8.37	8.00	7.47	7.34	8.96	7.16
600	10.92	10.63	10.03	10.42	10.32	10.53
800	11.66	11.39	10.41	10.76	10.86	11.05

The losses of water at various temperatures up to 800° C., given in Table LXXV confirm that the fine fractions from all the samples are very similar.

It is interesting to compare the analyses of the fine fractions with those of similar material prepared from shales and clays by other investigators. Grim, Bray, and Bradley (1937) found a micaceous mineral in the fine colloid fraction isolated from shales, clays and weathered tills, to which they gave the name "illite". Some of their analyses of illite are given in Table LXXVI, which also includes the average of the analyses of the fine fractions prepared from the South Wales clods and roof. The $\text{SiO}_2 : \text{Al}_2\text{O}_3$ ratios of the illite are greater than those of the fine fractions, although neither set of samples contains more than 2 per cent. of quartz. The average analysis of the fine fractions most resembles Grim's sample 5, Table LXXVI, except for the high percentage of Fe_2O_3 , which may be due to limonitic material. Generally speaking, the illite recovered by Grim, Bray, and Bradley contains more K_2O and much less Na_2O than do the present fine fractions.

The dehydration data are only slightly different for the two sets of samples, in that the fine fractions contain a little more water (H_2O —) than the illite. The data suggest that the fine fractions might contain some kaolinite, but too much

importance must not be attached to this, because it has been shown by other workers that the fineness of grinding and other factors affect the shape of the dehydration curve.

TABLE LXXVI
Chemical analyses of illite

Sample No. :	1.	2.	5.	Average analysis of fine fractions.
SiO ₂	50.10	51.22	44.01	45.82
Al ₂ O ₃	25.12	25.91	26.81	31.37
Fe ₂ O ₃	5.12	4.59	11.99	2.30
FeO	1.52	1.70	—	—
MgO	3.93	2.84	2.43	1.44
CaO	0.35	0.16	0.11	0.05
Na ₂ O	0.05	0.17	0.07	0.89
K ₂ O	6.93	6.09	4.78	5.25
TiO ₂	0.50	0.53	0.64	0.54
Ignition loss*	6.82	7.49	9.19	12.60
Total	100.44	100.70	100.03	100.26
H ₂ O +	7.18	7.14	8.03	7.93
H ₂ O -	1.90	1.45	2.53	3.09
SiO ₂ /R ₂ O ₃	3.00	3.02	2.17	2.32
SiO ₂ /Al ₂ O ₃	3.39	3.36	2.79	2.48

* The loss on ignition values for samples 1, 2, and 5 are based on material dried to 110° C.

1. Fine colloid fraction, Maquoketa (Ordovician) shale, near Gilead, Calhoun County, Ill.
2. Fine colloid fraction, Pennsylvanian underclay, near Fithian, Vermilion County, Ill.
5. Fine colloid fraction, Pennsylvanian shale, near Petersburg, Menard County, Ill.

TABLE LXXVII
Interplanar spacings (d) and intensities (Int) of X-ray diffraction lines of fine fractions and illite

Fine fraction.		Illite. Maegdefrau and Hofmann (1937).		Illite. Grim, Bray and Bradley (1937).		Indices.
d.	Int.	d.	Int.	d.	Int.	
10.0	v.s.	10.1	s.	10.0	s.	002
5.0	m.	4.9	m.	5.0	w.	004
4.46	v.s.	4.45	v.s.	4.47	s.	110
—	—	—	—	*4.11	v.w.	022
—	—	3.67	v.w.	*3.7	v.w.	023
—	—	—	—	*3.4	v.w.	114
3.32	v.s.	3.31	m.s.	3.31	m.	006
—	—	—	—	*3.2	v.w.	114
2.97	v.w.	3.05	v.w.	2.98	w.	025
2.80	v.w.	—	—	2.84	v.w.	115
2.55	v.s.	2.57	v.s.	2.56	s.	202
2.44	w.	2.47	w.	2.44	w.	133
2.37	w.m.	2.37	m.	2.38	m.	133
2.23	w.	2.25	w.	2.24	m.	221
2.17	w.	—	—	2.18	w.	223
2.14	m.	2.13	—	2.11	w.	043
1.98	m.	2.00	w.	1.98	m.	0010
1.64	m.	1.64	m.	1.64	w.	312
1.49	v.s.	1.50	s.	1.50	s.	060
1.34	w.	—	—	1.34	v.w.	335
1.29	m.	1.30	m.	1.29	m.	400
1.24	w.	1.25	w.	1.24	w.	0016

v.s. = very strong. s. = strong. m.s. = medium-strong. m. = medium.
w.m. = weak-medium. w. = weak. v.w. = very weak.

* Reflexions measured on aggregate diagrams, but not clearly observed on powder diagrams.

(2) *X-ray Diffraction Analyses*

All the fine fractions gave identical powder diagrams, showing large amounts of a mineral of the mica group and small amounts of a mineral of the kaolin group. No quartz nor carbonate lines were seen. The data for the mica closely resemble those reported by Grim *et al.* (1937) for illite, and by Maegdefrau and Hofmann (1937) for "glimmerton". Aggregate diagrams confirmed the presence of much mica, and showed slight variations in the intensities of the kaolin lines relative to the mica lines. Table LXXVII shows interplanar spacings and intensities of a typical powder diagram, and the data for illite and "glimmerton" for comparison.

Further attempts at separating the kaolin from the mica by gravity separation or sedimentation were unsuccessful, but the amount of kaolin in the samples could be estimated by comparison with aggregate diagrams of standard mixtures of kaolin-free illite (from Grundy Co., Illinois)* and kaolin of comparable grain-size. It was estimated that the samples from collieries A.1 and A.3 contained between 5 and 10 per cent., and all others between 10 and 20 per cent. of kaolin. Diagrams of aggregates heated to 500° C. showed no kaolin lines, whereas the mica lines persisted. The apparent absence of quartz was checked by a "free silica" determination (Shaw, 1934) on one sample. It revealed the presence of 1.5 per cent. of quartz.

The fine fractions seem, therefore, to contain chiefly a mineral of the mica group, similar to illite, accompanied by about 10 to 15 per cent. of kaolin and less than 2 per cent. of quartz. Other workers describing coal measure shales and the minerals found in the lung residues of South Wales coal miners have used the terms "sericite" or "secondary mica" to describe a mineral similar to or identical with the illite of the fine fractions. For the purpose of calculating the mineral composition of the roofs and clods, and the mineral matter in the coal, it has been assumed that the fine fractions all contain 10 per cent. of kaolin and 1 per cent. of quartz. On these assumptions, the average analysis of the illite itself at 105° is:—

	Per cent.
SiO ₂	47.55
Al ₂ O ₃	32.45
FeO	1.85
Fe ₂ O ₃	0.76
MgO	1.70
CaO	0.06
Na ₂ O	1.05
K ₂ O	6.22
TiO ₂	0.64
H ₂ O + 105° C.	7.73

(D) *Calculated Mineralogical Composition of the Roofs*

The mineralogical composition of the roof samples has been calculated on the assumption that all the SiO₂, Al₂O₃, K₂O and Na₂O in the samples are present as illite, kaolin (Al₂O₃, 2SiO₂, 2H₂O) and quartz. The excess calcium and magnesium are assumed to be present as carbonates, and any CO₂ still unaccounted for to be iron carbonate. Any Fe₂O₃ unaccounted for is given as such, although it may be present in the roof as a hydrated iron oxide (see report by Brammall and Leech, p. 136). The P₂O₅ is allocated to apatite and the TiO₂ to rutile. The mineralogical composition is reported on the air-dried basis.

No fine fractions were recovered from the roofs, with the exception of one from S.4; consequently, it has been necessary, when calculating the amounts

* The authors are indebted to Dr. Grim for supplying samples of illite.

of illite present, to use the analyses of the fine fractions recovered from the clods, and the percentages have been obtained by dividing the percentages of $K_2O + Na_2O$ in the roofs by the percentages of $K_2O + Na_2O$ in the fine fractions. To calculate the amount of illite in A.5 and A.6 roofs, the analysis of the A.3 District 2 clod fine fraction has been used, and for B.2 roof the analysis of the fine fraction from B.3 clod.

All mineral percentages calculated in this way can be considered only as approximations, particularly as the ratios of K_2O to Na_2O in the roofs are less than those in the fine fractions. The results of these calculations are useful, however, for a comparison of the strata from different localities, although they necessarily ignore certain differences described in the petrological report (Brammall and Leech) e.g., they do not distinguish primary from secondary quartz, nor is any allowance made for an amorphous groundmass.

TABLE LXXVIII

Calculated mineralogical composition of the roofs per cent. of air-dried sample

Colliery :	A.1.	A.2.	A.3.	A.5.		A.6.	S.4.	B.2.	B.3.
				Dist. 1.	Dist. 2.				
<i>Calculated from chemical analysis :</i>									
Illite	42.4	69.8	51.1	51.4	42.4	53.8	66.3	59.0	66.0
Kaolin	4.8	7.8	5.8	5.8	4.8	6.1	7.5	6.6	7.4
Quartz	45.0	18.6	31.2	27.0	43.7	27.2	16.3	26.2	21.6
Apatite	0.4	0.4	0.4	0.5	0.5	0.4	0.6	0.4	0.3
Calcium carbonate..	1.8	Nil	Nil	0.4	0.3	0.3	Nil	Nil	Nil
Magnesium carbonate	1.4	1.1	1.4	2.1	1.4	2.0	0.7	1.4	1.0
Iron carbonate ..	5.1	4.0	7.0	5.5	5.0	3.7	8.5	6.7	6.0
Fe ₂ O ₃	0.5	1.6	1.5	2.3	2.0	4.0	Nil	Nil	0.1
Rutile	0.6	0.4	0.7	0.7	0.7	0.6	0.4	0.5	0.5
Total	102.0	103.7	99.1	95.7	100.8	98.1	100.3	100.8	102.9
Free silica by rational analysis	46	19	32	26	48	26	17	25	22
<i>X-ray diffraction analysis :</i>									
<i>Powder diagrams :</i>									
Quartz	S	M	S	—	—	—	M	—	M
Mica and kaolin ..	M	M	M	—	—	—	M	—	M
Carbonates	W	W	W	—	—	—	M	—	W
<i>Aggregate diagrams :</i>									
Mica	S	S	—	—	—	—	S	—	S
Kaolin	W	W	—	—	—	—	W	—	M

S = strong. M = medium. W = weak.

The calculated mineral composition of the roofs is given in Table LXXVIII which also includes the percentage of "free silica" determined by rational analysis (Shaw, 1934).

In the method of rational analysis, Shaw assumes the Al_2O_3 in the residue to be feldspar and, in correcting for it, uses the factor 5.41. There are only rare traces of feldspar in these rocks and, apart from quartz and some Fe_2O_3 , the residue consists chiefly of undecomposed mica. For the purpose of calculating the "free silica", the factor 2.79 has therefore been used instead of 5.41, except for the few samples, the residues for which contained appreciable quantities of Fe_2O_3 . The total silica and alumina in the residues from these were determined and the free silica was taken to be the total silica less 1.46 times the Al_2O_3 .

The main constituents, illite, kaolin and quartz, amount to approximately 90 per cent. of the samples. The carbonates are minor constituents and, except in the case of A.1, the amount of calcium carbonate is negligible. There is a small amount of magnesium carbonate, and from 4 to 8.5 per cent. of iron carbonate.

The calculated percentages of quartz are in good agreement with the percentages of "free silica" determined by rational analysis. This, however, cannot be taken as proof that the basis of the calculations is necessarily correct. If it had been assumed that the K_2O , Al_2O_3 , and SiO_2 , were present as normative muscovite (K_2O , $3Al_2O_3$, $6SiO_2$, $2H_2O$), kaolin (Al_2O_3 , $2SiO_2$, $2H_2O$) and quartz (SiO_2), then the calculated amounts of quartz would also in most instances have been in fair agreement with the determined "free silica" values.

The calculated amount of kaolin in all the samples is of the order of 10 per cent. or less, in agreement with the X-ray diffraction analyses. Illite and quartz, the two main constituents, account for 80-85 per cent. of the roofs.

The percentage of quartz in the roofs may show a slight increase, and that of illite a corresponding decrease, with increasing rank of the coal, at the places where the samples were taken, but the relationship is not clearly established. Samples from A.1 and A.5 District 2 contain more quartz than any of the others, but there is as much quartz in the roof above the bituminous coal at B.2 as there is above the anthracite seam at A.6.

(E) *Calculated Mineralogical Composition of the Clods*

The mineralogical composition of the clods, calculated in the same way as that adopted for the roofs, is shown in Table LXXIX, which also shows the results of "free silica" determinations. As no fine fractions were recovered from A.5, A.6, S.4, and B.2 clods, the analysis of the fine fraction of the clod from A.3 District 2 was used for calculating the composition of samples A.5 and A.6, the fine fraction from the roof of S.4 for the clod S.4, and the fine fraction from B.3 clod for the clod B.2.

The agreement between the $K_2O : Na_2O$ ratios of the clods and of the fine fractions is much better than in the case of the roofs and the fine fractions, with the exception of S.4, where the clod or bast contained only 33.7 per cent. of ash and the fine fraction was prepared from the roof material.

The major constituents of the clods are again illite and quartz; kaolin and carbonates are present in smaller amounts. In most of the samples there is no calcium carbonate and less than 1.0 per cent. of magnesium carbonate. On an average, there is less iron carbonate in the clods than in the corresponding roof samples.

The determined "free silica" is in good agreement with the calculated amount of quartz.

Some of the clods contain a considerable amount of coaly matter; therefore, in order to compare the clods with each other and with the corresponding roofs, the amounts of illite, kaolin and quartz have been estimated as percentages of the total calculated minerals, and the results are given in Table LXXX.

As in the roofs, the kaolin is a minor constituent in the clods, and the chief minerals are illite and quartz. There is again no definite relationship between the amount of quartz and the rank of the coal at the places where the samples were taken, and the clods above the bituminous seams contain as much quartz as those above the anthracite seams.

A comparison of the illite, kaolin and quartz in the clods and the roofs is given in Tables LXXXI and LXXXII, which also include data for the incidences of pneumokoniosis. With the exception of the samples from A.5 District 1 and from B.2, all the clods contain relatively less quartz and more illite than the corresponding roofs, and in some instances these differences are considerable.

The results obtained for the roofs and clods may be summarised as follows. All roofs and clods are similar in consisting mainly of illite and quartz, with minor quantities of kaolin and carbonates. The proportions of quartz vary considerably, and are, on the whole, slightly higher for the roofs than for the clods. There is no regular variations of the percentages of quartz with the rank

TABLE LXXIX

Calculated mineralogical composition of the clods, per cent. of air-dried samples

Colliery :	A.1.	A.2.	A.3.		A.5.		A.6.	S.A.	B.2.	B.3.	
			Dist. 1.	Dist. 2.	Dist. 1.	Dist. 2.					
<i>Calculated from chemical analysis :</i>											
Illite	66.0	71.6	77.3	71.8	47.7	57.0	37.1	28.2	37.8	69.8	
Kaolin	7.4	8.0	8.7	8.1	5.4	6.4	4.2	3.2	4.3	7.9	
Quartz	24.5	14.2	8.0	17.1	30.1	27.4	7.7	5.6	20.9	9.1	
Pyrite	ND	0.3	Nil	Trace	ND	ND	1.7	ND	ND	ND	
Apatite	Nil	0.1	0.5	0.5	0.5	0.4	0.2	0.1	0.3	0.5	
Calcium carbonate	Nil	Nil	Nil	Nil	0.2	Nil	0.1	Nil	Nil	Nil	
Magnesium carbonate	0.4	0.7	0.3	0.5	1.8	1.4	0.3	Trace	0.4	0.8	
Iron carbonate	Nil	2.4	0.8	4.5	4.2	1.8	Nil	Nil	0.7	4.5	
Chlorite	0.2	Nil	Nil	Nil	Nil	Nil	0.7	Nil	Nil	Nil	
Fe ₂ O ₃	1.4	0.8	0.4	0.1	3.8	3.7	0.3	Nil	Nil	Nil	
Rutile	0.6	0.3	0.1	0.1	0.7	0.7	0.2	0.1	0.4	0.2	
Total	100.5	98.4	96.1	102.7	94.4	98.8	52.5	37.2	64.8	92.8	
Free silica by rational analysis	26	15	10	18	31	28	4	ND	16	11	
<i>X-ray diffraction analysis :</i>											
Powder diagrams	Quartz	S	M	M	M	—	—	—	M*	M	M
	Mica and Kaolin	M	M _h	M	M	—	—	—	M*	M	M
	Carbonates	Tr	Tr	Tr	W	—	—	—	Tr*	Tr	W
Aggregate diagrams	Mica	S	S	S	S	—	—	—	M*	M	S
	Kaolin	W	W	VW	W	—	—	—	W*	W	M

S = strong.

M = medium

W = weak.

VW = very weak.

Tr. = trace.

* Analysis of the ash prepared at 380° C.

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of the coal, although there is a tendency for the roofs above the anthracite seams to contain slightly more quartz than the roofs above the others, but it must be remembered that the number of samples examined is small. The chemical composition of the illite is constant, except for a decrease of sodium content with decreasing rank.

TABLE LXXX
Illite, kaolin and quartz in the clods as per cent. of total minerals

Colliery :	A.1.	A.2.	A.3.		A.5.		A.6.	S.4.	B.2.	B.3.
			Dist. 1.	Dist. 2.	Dist. 1.	Dist. 2.				
Illite ..	66.0	72.8	80.4	71.8	50.5	57.7	70.7	75.8	58.3	75.2
Kaolin ..	7.4	8.1	9.1	8.1	5.7	6.5	8.0	8.6	6.6	8.5
Quartz ..	24.5	14.4	8.3	17.1	31.9	27.7	14.7	15.1	32.3	9.8

TABLE LXXXI
Illite, kaolin and quartz in roofs and clods as per cent. of air-dried samples

	Illite.		Kaolin.		Quartz.		Incidence of pneumo-koniosis.
	Roof.	Clod.	Roof.	Clod.	Roof.	Clod.	
A.1 ..	42.4	66.0	4.8	7.4	45.0	24.5	High
A.3, Dist. 1 ..	51.1	77.3	5.8	8.7	31.2	8.0	High
A.3, Dist. 2 ..	—	71.8	—	8.1	—	17.1	High
A.6 ..	53.8	37.1	6.1	4.2	27.2	7.7	High
A.2 ..	69.8	71.6	7.8	8.0	18.6	14.2	Low
A.5, Dist. 1 ..	51.4	47.7	5.8	5.4	27.0	30.1	Low
A.5, Dist. 2 ..	42.4	57.0	4.8	6.4	43.7	27.4	Low
S.4 ..	66.3	28.2	7.5	3.2	16.3	5.6	Low
B.2 ..	59.0	37.8	6.6	4.3	26.2	20.9	Low
B.3 ..	66.0	69.8	7.4	7.9	21.6	9.1	Low

TABLE LXXXII
Illite, kaolin and quartz in roofs and clods as per cent. of total minerals

	Illite.		Kaolin.		Quartz.		Incidence of pneumo-koniosis.
	Roof.	Clod.	Roof.	Clod.	Roof.	Clod.	
A.1 ..	42.4	66.0	4.8	7.4	45.0	24.5	High
A.3, Dist. 1 ..	51.6	80.4	5.9	9.1	31.5	8.3	High
A.3, Dist. 2 ..	—	71.8	—	8.1	—	17.1	High
A.6 ..	54.8	70.7	6.2	8.0	27.7	14.7	High
A.2 ..	69.8	72.8	7.8	8.1	18.6	14.4	Low
A.5, Dist. 1 ..	53.7	50.5	6.1	5.7	28.2	31.9	Low
A.5, Dist. 2 ..	42.4	57.7	4.8	6.5	43.7	27.7	Low
S.4 ..	66.3	75.8	7.5	8.6	16.3	15.1	Low
B.2 ..	59.0	58.3	6.6	6.6	26.2	32.3	Low
B.3 ..	66.0	75.2	7.4	8.5	21.6	9.8	Low

THE MINERAL MATTER IN THE COAL

In the standard methods of coal analysis the amount of ash is determined by incinerating the coal at 800° C. until the weight of the residue is constant. The ash so obtained differs from the mineral matter in the coal by an amount depending on the changes which the mineral matter has undergone during incineration, such as (i) the loss of water of constitution, (ii) the conversion of iron sulphide to ferric oxide and sulphur dioxide, (iii) the loss of CO₂ by the carbonates, (iv) the fixing of SO₃, mainly by the lime in the ash, and (v) the

decomposition of the chlorides (King, Maries and Crossley, 1936). The amount of mineral matter is usually greater than the determined ash, but until such time as the necessary analytical data are available to calculate the mineral matter, a comparison of various coals can be made only on the basis of the percentage of ash in the air-dried coal.

In the course of the physical and chemical survey of the seams in South Wales, the Fuel Research organisation of the Department of Scientific and Industrial Research has examined a large number of pillar samples, representative of the full thicknesses of many seams ; the percentages of ash determined in 238 whole seam pillar samples, taken from various parts of the South Wales coalfield and representative of the full range of coals, are classified in the following table.

TABLE LXXXIII
Ash in pillar samples
Per cent. of total samples examined

Volatile matter.	Less than 10 per cent.	10-19.9 per cent.	20-29.9 per cent.	Greater than 30 per cent.
No. of samples :	43.	78.	61.	56.
Ash, per cent. air-dried coal.	Per cent. of samples.	Per cent. of samples.	Per cent. of samples.	Per cent. of samples.
10-10.9	—	—	—	7.1
9- 9.9	—	—	—	} 5.4
8- 8.9	—	—	—	
7- 7.9	—	2.5	11.8		14.3
6- 6.9	2.3	1.3	18.0	19.6
5- 5.9	7.0	11.5	11.5	23.2
4- 4.9	20.9	24.4	19.7	8.9
3- 3.9	34.9	34.6	26.1	12.5
2- 2.9	27.9	24.4	13.3	8.9
1- 1.9	7.0	1.3		

It will be seen from this analysis of results that, in general, there is an increase in the percentage of ash with an increase in the volatile matter of the coal ; but, even so, there are some seams with a high percentage of volatile matter which contain as low a percentage of ash as do the anthracites.

For the purposes of the present investigation, pillar samples from 18 collieries have been examined (see pp. 155-6). Their ash percentages, given in the second column of Table LXXXIV, confirm the generalisation that the lower rank coals in South Wales contain, on an average, a higher percentage of ash than the high rank coals.

In addition to this increase of percentage of ash with increase in volatile matter, mention must be made of the variation in the distribution of ash in the seam from the floor to the roof. The ash in many instances is very unevenly distributed, and much of the seam contains far less ash than the average. It is often found that the ash is concentrated in fairly narrow and well-defined bands.

The difficulties arising out of the complexity and heterogeneity of the mineral matter in the coal are very great, but some simplification is obtained by considering separately the inherent and the extraneous mineral matter. The inherent minerals may be defined as the constituents of the original plants or, rather, the residue of these constituents, because it is likely that some of the original plant mineral matter has been leached out during or subsequent to the period of deposition of the seam.

The extraneous mineral matter would consist of the detritus in the form of clay or other water-borne shale-like materials, siderite, pyrite, ankerite, calcite,

dolomite, sulphates and chlorides. The clay or shale-like material was probably deposited contemporaneously with the organic matter and is now found in the seam as thin shale partings or small lenses of carbonaceous shale-like material; in other instances it is intimately mixed with the coal and appears as a dull band, which often merges into layers of clod or bast. The nodular pyrite and siderite (the brass-stone of South Wales), particularly the latter, were also in all probability deposited from solution at the time when the seam was being formed. The ankerite, calcite and dolomite and thin films of pyrite which are found in vertical cleavage planes, and the pyritised fusian, are most likely of secondary origin and have been deposited from circulating and infiltrating water subsequent to the formation and consolidation of the seam (Bray, 1941).

It may be impossible to make a clean separation of the inherent and extraneous mineral matter as defined above, but a sample of the extraneous mineral matter can be obtained by floating the ground sample of coal in a solution of specific gravity of 1.60, when it will be concentrated in the heavy fraction.

The 18 samples discussed in this report were ground to pass an $\frac{1}{8}$ in. screen floated in a mixture of benzene and carbon tetrachloride of specific gravity 1.60, and allowed to stand until there was a clear division between the sinks and the floats.

To obtain a coal fraction from which an approximation to the inherent mineral matter could be obtained, the coal floating in the solution of specific gravity 1.60 was refloat in a solution of lower specific gravity. The selection of the specific gravity of this solution is partly dependent on the rank of the coal—the higher the rank of the coal, the higher the specific gravity. The specific gravities of the solutions used are given in Table LXXXIV; they varied for the anthracites from 1.40 to 1.45, and for the bituminous coals from 1.30 to 1.35. These specific gravities were the lowest commensurate with yielding sufficient coal to give enough ash for analysis. It must be remembered that the fractionation adopted is arbitrary, because if the coal had been ground to a finer state of division, fractions containing less ash than those examined would in some instances have been obtained; it is considered, however, that the samples obtained are comparable. For the purposes of this report the mineral matter in these light fractions is considered as inherent. It has not yet been possible to analyse the ash in the fractions of intermediate specific gravity (referred to in Table LXXXIV as "middlings"), but their composition is likely to be intermediate between that of the lighter and the heavier fractions. The relative proportions of the three fractions, and their ash percentages, are given in Table LXXXIV. On an average of the samples examined, the coal seam material contains 4.6 per cent. of ash. The inherent mineral matter accounts for 24.8 per cent., and the extraneous mineral matter for 33.2 per cent. of this ash. The efficiency of the separation of the extraneous mineral matter may be judged from the fact that, on an average, one third of the total ash of the seam is contained in 3.7 per cent. of the seam material of specific gravity greater than 1.60.

(A) *The Inherent Mineral Matter*

The ash percentage of the lightest coal fractions is small, and for most of the samples examined it lies between 0.8 and 1.8; only four of the light fractions contain more than 2.0 per cent. of ash.

(1) *Chemical Analyses.*—The chemical analyses of 14 samples of inherent ash are given in Table LXXXV. It will be noted that for some of the ashes the "totals" are approximately 97–98 per cent., but no explanation can be put forward to account for this. The same technique were adopted as for the roofs, clods and extraneous ash, when the "totals" were quite satisfactory. This aspect of the ash analysis will be a subject for further study.

TABLE LXXXIV
Gravity separation of seam pillar samples
Yields and ash percentages

Colliery.	Per cent. of ash in seam pillar samples.	Yields, per cent. of air-dried coal.			Ash, per cent. of air-dried fractions.			Ash in fractions as per cent. of ash in seam pillar sample.		
		Floats.	Middlings.	Sinks.	Floats.	Middlings.	Sinks.	Floats.	Middlings.	Sinks.
A.1	2.5	81.4 (1)	15.8	2.8	0.8	6.5	29.8	26	41	33
A.2	2.5	85.6 (1)	12.1	2.3	1.1	7.4	28.6	38	36	26
A.3	3.5	52.4 (2)	43.9	3.7	1.3	3.5	34.7	19	44	37
A.5	4.3	56.1 (2)	40.7	3.2	1.3	5.7	38.7	17	54	29
A.6	6.0	79.8 (2)	12.4	7.8	1.5	7.7	49.4	20	16	64
A.7	3.5	83.4 (2)	14.7	1.9	1.8	9.0	35.2	43	38	19
A.8	2.8	91.8 (2)	6.1	2.1	1.5	12.0	33.3	49	26	25
A.9*	2.4	61.6 (2)	35.8	2.6	0.5	3.7	30.1	13	55	32
S.3	3.3	73.3 (3)	23.7	3.0	1.1	5.2	41.9	24	38	38
S.4	2.1	92.5 (2)	5.4	2.1	0.9	5.4	46.8	40	14	47
B.1	6.8	74.7 (3)	21.3	4.0	2.9	14.3	39.8	32	45	23
B.2	4.3	47.8 (5)	47.8	4.4	1.4	3.9	40.3	16	43	41
B.3	5.2	53.3 (5)	42.9	3.8	1.6	6.9	36.9	16	57	27
B.4*	7.5	42.0 (4)	55.4	2.6	2.7	9.3	47.3	15	69	16
B.5*	7.4	40.3 (5)	52.0	7.7	1.7	5.1	52.7	9	36	55
B.6*	5.1	51.8 (5)	44.2	4.0	1.2	6.5	40.5	12	56	32
B.7*	6.2	56.7 (4)	38.9	4.4	2.1	8.2	41.6	19	51	30
B.8*	6.6	77.2 (3)	18.9	3.9	3.4	12.6	40.7	40	36	24
Mean	4.6	66.8	29.6	3.7	1.6	7.4	39.4	25	42	33

- (1) Separation made in liquid of specific gravity of 1.45.
- (2) Separation made in liquid of specific gravity of 1.40.
- (3) Separation made in liquid of specific gravity of 1.35.
- (4) Separation made in liquid of specific gravity of 1.32.
- (5) Separation made in liquid of specific gravity of 1.30.

* Not included in the Medical Survey.

TABLE LXXXV
Analyses of the inherent ash of 14 samples

Colliery :	A.1.	A.2.	A.3.	A.5.	A.6.	A.7.	A.8.	A.9.	S.3.	S.4.	B.2.	B.3.	B.4.	B.5.
Ash, per cent. air-dried coal ..	0.78	1.12	1.29	1.34	1.48	1.76	1.49	0.48	1.06	0.88	1.42	1.60	2.74	1.69
CO ₂ , per cent. air-dried coal ..	0.11	0.21	0.13	0.10	0.24	0.13	0.17	0.11	0.05	0.14	0.06	0.08	0.06	0.08
Sulphate sulphur, per cent. air-dried coal	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.01	Trace	0.02	0.01	0.01	0.03
Pyritic sulphur, per cent. air-dried coal	Nil	Nil	0.02	0.09	0.10	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0.02	0.01
Per cent. of ash :														
SiO ₂	38.85	35.82	38.15	20.43	19.56	37.50	29.82	32.94	29.11	36.31	28.44	35.51	36.53	30.66
TiO ₂	1.02	0.94	0.92	1.15	1.16	1.28	1.68	1.40	1.64	1.24	1.60	1.18	0.86	1.16
Al ₂ O ₃	39.26	39.14	34.96	35.85	29.20	44.95	41.92	38.62	43.64	37.55	43.21	42.81	46.71	41.30
Fe ₂ O ₃	8.30	9.57	13.18	23.01	29.71	3.60	6.23	13.22	6.12	12.99	4.59	3.41	3.70	6.60
CaO	3.15	3.71	2.18	6.26	6.41	2.59	4.91	3.73	4.59	2.83	6.33	5.42	4.51	5.44
BaO	Nil	Nil	0.30	0.04	0.29	0.03	0.03	Nil	0.11	0.25	0.05	0.41	0.03	0.02
MgO	1.28	1.36	1.52	1.47	2.69	0.72	1.39	1.65	1.02	1.74	1.58	1.62	0.81	1.68
K ₂ O	0.85	0.45	1.12	0.50	0.69	0.30	0.37	0.30	0.32	0.88	0.46	0.40	0.04	0.39
Na ₂ O	4.57	3.14	3.08	2.31	2.27	3.51	3.25	2.91	3.20	2.21	2.53	1.93	0.64	2.29
SO ₂	1.29	1.34	1.21	2.50	6.76	0.83	3.74	2.83	3.00	0.99	3.37	2.84	0.64	3.19
P ₂ O ₅	0.21	2.20	1.59	2.92	0.27	2.52	2.87	0.43	3.97	1.36	3.91	2.17	3.07	3.78
Loss on ignition at 800° C. ..	0.93	1.13	1.06	1.25	0.60	0.50	0.94	0.68	0.81	0.92	0.74	1.48	0.27	0.55
Total	99.71	98.80	99.27	97.69	99.61	98.33	97.15	98.71	97.53	99.27	96.81	99.18	97.81	97.06

Mr. G. N. Perkins, of the Chemical Inspection Department, Ministry of Supply, Cardiff, kindly analysed samples A.2, A.8 and B.2 spectrographically, and found strontium, lead, nickel, chromium, tin, molybdenum, cobalt, manganese, copper, tungsten, vanadium, lithium and boron to be present as minor constituents. The amounts of these elements were estimated as 0.1 per cent. or less. Special attention was given to detection of lithium and boron, and it was found that the latter increases from samples A.2 to A.8 and again to B.2, the indication being that it is 0.1, 0.2 and 0.5 per cent., respectively. These percentages are only approximate and will be checked later by gravimetric determinations. A rough value for the lithium content is 0.1 per cent. for all samples.

The amount of Fe_2O_3 , present as pyrite and carbonate, varies greatly. This may indicate that in some instances there has not been a complete removal of the extraneous mineral matter.

TABLE LXXXVI
Selected constituents of inherent ash

Colliery.	$SiO_2 + Al_2O_3 + K_2O + Na_2O$. Per cent. of total ash.	Per cent. of $SiO_2 + Al_2O_3 + K_2O + Na_2O$				Mols SiO_2		Incidence of pneumoconiosis.
		SiO_2	Al_2O_3	K_2O	Na_2O	Mols Al_2O_3		
A.1 ..	83.5	46.5	47.0	1.0	5.5	1.68	High	
A.2 ..	78.6	45.6	49.8	0.6	4.0	1.55	Low	
A.3 ..	77.3	49.3	45.2	1.5	4.0	1.85	High	
A.5 ..	59.1	34.6	60.7	0.9	3.9	0.97	Low	
A.6 ..	51.7	37.8	56.5	1.3	4.4	1.14	High	
A.7 ..	86.3	43.5	52.1	0.4	4.1	1.42	Medium	
A.8 ..	75.4	39.6	55.6	0.5	4.3	1.21	Medium	
A.9* ..	74.8	44.1	51.7	0.4	3.9	1.45	High*	
S.3 ..	76.3	38.2	57.2	0.4	4.2	1.13	Medium	
S.4 ..	77.0	47.2	48.8	1.1	2.9	1.64	Low	
B.2 ..	74.6	38.1	57.9	0.6	3.4	1.12	Low	
B.3 ..	80.7	44.0	53.1	0.5	2.4	1.41	Low	
B.4* ..	83.9	43.5	55.7	0.1	0.8	1.33	Low*	
B.5* ..	74.6	41.1	55.3	0.5	3.1	1.26	Low*	

Mols SiO_2 High incidence collieries .. 1.68, 1.85, 1.14, 1.45.
Medium incidence collieries 1.42, 1.21, 1.13.

Mols Al_2O_3 Low incidence collieries .. 1.55, 0.97, 1.12, 1.41, 1.33, 1.26, 1.64.

* Not included in the Medical Survey. The incidences quoted are those of certified silicosis.

In Table LXXXVI the SiO_2 , Al_2O_3 , K_2O and Na_2O , which, on an average, account for 75 per cent. of the ash, are expressed as percentages of the sum of these oxides. It will be seen that, on this basis, there is not a very great difference between any of the samples, but it is interesting to note that, in contrast to the roof and clod analyses, the $SiO_2 : Al_2O_3$ ratio of all the samples is less than 2 and that there is much more soda than potash present.

(2) X-ray Diffraction Analyses and Mineralogical Composition.—The X-ray diffraction analyses of the acid-treated ash residues prepared at 380° C. are given for six of the samples in Table LXXXVII; they show the main constituent to be kaolin. A further distinction could be made, as some of the samples had a diffraction pattern similar to that of kaolinite, some had one similar to halloysite and others corresponded to a mixture of both these members of the kaolin group. The analyses also showed small amounts of mica and traces of quartz in the inherent mineral matter. The percentages of CO_2 , pyritic sulphur and sulphate sulphur in the air-dried coal samples, and the percentage of P_2O_5 in the ash, are sufficient to account for all the CaO as apatite and calcium carbonate, the MgO as magnesium carbonate and the Fe_2O_3 as pyrite and iron carbonate. In most of the samples the quantities of these minerals

TABLE LXXXVII
Inherent mineral matter.
 (Minerals as per cent. of minerals containing SiO_2 , Al_2O_3 , K_2O and Na_2O)

<i>Incidence of pneumokoniosis</i>		H	L	H	L	H	M	M	H*	M	L	L	L	L*	L*
<i>Colliery</i>		A.1.	A.2.	A.3.	A.5.	A.6.	A.7.	A.8.	A.9.	S.3.	S.4.	B.2.	B.3.	B.4.	B.5.
Calculated from Chemical Analysis	Kaolin	73	79	70	54	52	78	69	78	67	64	51	76	82	76
	Illite	15	9	22	13	21	5	7	6	6	17	11	7	1	9
	Quartz	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	4	Nil	Nil	Nil	Nil
	Al_2O_3	8	10	5	29	23	14	20	13	23	13	35	14	17	13
	Na_2O	5	3	3	3	4	4	4	3	4	2	3	2	1.	3
X-ray Diffraction Analysis	Kaolin	H	H	H	—	—	—	H	—	—	H	—	H	—	—
	Mica	L	L	M/L	—	—	—	Nil	—	—	L	—	V.L.	—	—
	Quartz	V.L.	V.L.	V.L.	—	—	—	V.L.	—	—	L	—	V.L.	—	—
	Kaolinite type ..	L	M	L	—	—	—	L	—	—	M	—	M	—	—
	Halloysite type ..	H	M	H	—	—	—	H	—	—	M	—	M	—	—

H = high. M = medium. M/L = medium to low. L = low. V.L. = very low.

* Not included in the Medical Survey. The incidences are those of certified silicosis.

are small, but the fact that they are present at all emphasises the difficulty of making a complete separation of the extraneous from the inherent mineral matter. Dismissing these minerals, which are of small amount, it remains to account for the SiO_2 , Al_2O_3 , K_2O , and Na_2O .

In calculating the mineral composition from the ash analysis it has been assumed that the mica has the same composition as the illite in the clods and roofs. There is no proof from our data that the mica found in the samples is in fact illite, but the assumption seems reasonable. With this assumption, it is found that most of the Na_2O is unaccounted for. The identity of the soda mineral requires further study. The amount of water-soluble soda in the ashes is very small and not sufficient to suggest that all the soda unaccounted for is present in the coal as sodium chloride. The minerals of the kaolin group have been assumed to have the composition Al_2O_3 , 2SiO_2 , $2\text{H}_2\text{O}$.

The mineralogical composition calculated in this way is given in Table LXXXVII. Most of the mineral matter is kaolin; the amount of illite is less than 20 per cent. of the total, and in some samples as little as 5 to 10 per cent. This is in marked contrast to the roofs and clods, where the major constituents are quartz and illite and the amount of kaolin is small.

All the samples contain some Al_2O_3 unaccounted for, and this may be present in the inherent mineral matter as free alumina, or else the kaolinite and halloysite may contain a higher proportion of alumina than corresponds to their theoretical composition. Possibly a yet unidentified compound containing both Na_2O and Al_2O_3 exists. Several of the X-ray diffraction diagrams of samples of the inherent, as well as of the extraneous, mineral matter contained fairly strong lines which could not be identified, although comparisons were made with a number of minerals likely to occur in the samples.

Kaolin, the main siliceous constituent of the inherent ash, seems to be more of halloysite type in anthracite and of kaolinite type in non-anthracite; otherwise the inherent mineral matter in all the coals is of similar composition except for erratic variations in iron minerals.

(B) *The Extraneous Mineral Matter*

The percentage of ash in the heaviest coal fractions varies from 29 to 53. As would be expected, the extraneous mineral matter is a much more complex mixture than the inherent mineral matter.

(1) *Chemical Analyses.*—The analyses of the ashes of 18 samples, together with the percentages of CO_2 , pyritic sulphur and sulphate sulphur in the air-dried samples are given in Table LXXXVIII. The analyses differ from each other very considerably. The percentages of SiO_2 range between 10.3 and 41.5, and those of Al_2O_3 between 8.3 and 32.2. There is no regularity in the amounts of Fe_2O_3 , which may be as low as 8.9 per cent. of the ash and as high as 56.1 per cent. The amount of MgO is in all instances less than the amount of CaO in the ash, which tends to be higher in the ashes of the bituminous coals than in those of the anthracites. Even when the SiO_2 , Al_2O_3 , K_2O and Na_2O are expressed as percentages of the total of these oxides (Table LXXXIX), there is still a fairly wide range of results. The ratio $\text{SiO}_2 : \text{Al}_2\text{O}_3$ shows considerable variations; in one sample (A.3) it is as high as 3.4 and in another (A.7) as low as 1.2.

(2) *X-ray Diffraction Analyses and Mineralogical Composition.*—The X-ray diffraction analyses of the acid-treated ash residues prepared at 380°C . are shown in Table XCI. Kaolin is the main constituent and it is again possible to distinguish the kaolinite type, which is more prominent in the bituminous samples, from the halloysite type which prevails in the anthracite. Quartz and mica occur in several of the samples, but not in all.

TABLE LXXXVIII
Analyses of the extraneous ash of 18 samples

Colliery.	Ash, per cent. air-dried sample.	CO ₂ , per cent. air-dried sample.	Pyritic sulphur, per cent. air-dried sample.	Sulphate sulphur, per cent. air-dried sample.	Per cent. of Ash.											Losson ignition at 800° C.	Total.
					SiO ₂ .	TiO ₂ .	Al ₂ O ₃ .	Fe ₂ O ₃ .	CaO.	BaO.	MgO.	K ₂ O.	Na ₂ O.	SO ₃ .	P ₂ O ₅ .		
					A.1 ..	29.8	3.90	0.09	0.04	41.03	0.90	23.74	12.69	8.70	Nil			3.97	2.35	2.00	3.18	0.87	0.66	100.09
A.2 ..	28.6	3.45	0.29	0.04	36.01	1.20	32.22	8.88	8.16	Nil	3.45	1.16	1.84	4.39	1.79	0.80	99.90
A.3 ..	34.7	3.58	6.04	0.96	23.83	0.28	11.99	39.39	8.87	0.08	3.74	0.80	0.44	8.54	2.26	0.48	100.70
A.5 ..	38.7	7.08	3.66	0.10	19.07	0.56	18.56	25.04	16.01	Nil	4.45	1.13	0.93	2.91	5.74	5.03	99.43
A.6 ..	49.4	9.24	14.60	0.41	10.29	0.14	8.34	50.58	8.69	Nil	5.06	0.96	0.32	12.34	0.48	3.57	100.75
A.7 ..	35.2	12.06	0.18	0.05	17.22	0.22	24.29	20.96	19.80	0.06	9.06	0.64	1.13	3.50	1.93	0.71	99.52
A.8 ..	33.3	9.71	0.10	0.05	21.10	0.30	26.70	15.92	18.97	0.04	8.01	0.86	1.84	3.43	1.22	1.76	100.15
A.9 ..	30.1	2.78	7.61	0.81	22.37	0.50	15.43	43.43	5.67	Nil	2.45	1.55	0.55	6.69	0.70	1.15	100.49
S.3 ..	41.9	15.66	0.09	0.05	17.74	0.18	19.34	31.49	15.26	0.05	8.72	0.53	1.21	2.04	1.83	0.98	99.35
S.4 ..	46.8	ND	0.18	0.03	15.98	0.28	11.06	56.07	4.34	0.20	7.04	0.55	0.33	1.99	2.07	0.59	100.50
B.1 ..	39.8	9.40	0.09	0.08	26.70	1.20	25.99	9.28	15.86	Nil	7.23	1.84	0.91	2.85	4.19	2.09	98.14
B.2 ..	40.3	16.66	0.03	0.02	18.78	0.14	22.29	13.78	25.76	0.14	12.88	0.99	0.55	1.50	1.71	0.64	99.16
B.3 ..	36.9	14.54	0.05	0.04	21.25	0.36	21.11	10.21	26.20	0.12	13.20	1.06	0.43	1.83	2.12	0.77	98.66
B.4 ..	47.3	6.16	1.11	0.05	41.54	0.84	28.89	11.49	6.36	Nil	3.41	0.13	0.31	3.40	2.22	0.95	99.54
B.5 ..	52.7	10.92	6.06	0.66	21.43	0.22	18.46	20.30	14.33	0.03	8.35	0.69	0.11	12.27	0.48	1.60	98.27
B.6 ..	40.5	ND	ND	ND	16.07	0.28	11.03	41.05	10.40	0.02	5.83	1.68	0.49	10.16	0.19	2.63	99.83
B.7 ..	41.6	15.48	0.83	0.07	21.66	0.18	20.54	12.41	23.85	Nil	12.40	0.61	0.24	4.05	1.01	2.25	99.20
B.8 ..	40.7	16.12	0.95	0.05	18.97	0.20	17.95	12.58	25.47	Nil	12.80	0.62	0.76	4.61	0.72	4.27	98.95

TABLE LXXXIX

Selected constituents of extraneous ash

Colliery.	SiO ₂ +Al ₂ O ₃ +K ₂ O+Na ₂ O. Per cent. of total ash.	Per cent. of SiO ₂ +Al ₂ O ₃ +K ₂ O+Na ₂ O.				Mols SiO ₂	Incidence of pneumo-koniosis.
		SiO ₂ .	Al ₂ O ₃ .	K ₂ O.	Na ₂ O.	Mols Al ₂ O ₃	
A.1 ..	69.1	59.4	34.3	3.4	2.9	2.9	High
A.2 ..	71.2	50.6	45.2	1.6	2.6	1.9	Low
A.3 ..	37.1	64.3	32.4	2.2	1.2	3.4	High
A.5 ..	39.7	48.0	46.8	2.9	2.3	1.8	Low
A.6 ..	19.9	51.7	41.9	4.8	1.6	2.1	High
A.7 ..	43.3	39.8	56.1	1.5	2.6	1.2	Medium
A.8 ..	50.5	41.8	52.9	1.7	3.6	1.3	Medium
A.9* ..	39.9	56.1	38.7	3.9	1.4	2.5	High*
S.3 ..	38.8	45.7	49.8	1.4	3.1	1.6	Medium
S.4 ..	27.9	57.2	39.6	2.0	1.2	2.5	Low
B.1 ..	55.4	48.2	46.9	3.3	1.6	1.8	Low-medium
B.2 ..	42.6	44.1	52.3	2.3	1.3	1.4	Low
B.3 ..	43.9	48.5	48.1	2.4	1.0	1.7	Low
B.4* ..	70.9	58.6	40.8	0.2	0.4	2.5	Low*
B.5* ..	40.7	52.7	45.4	1.7	0.3	2.0	Low*
B.6* ..	29.3	54.9	37.7	5.7	1.7	2.5	High*
B.7* ..	43.1	50.3	47.7	1.4	0.6	1.8	Low*
B.8* ..	38.3	49.5	46.9	1.6	2.0	1.8	Low*

Mols SiO₂ High incidence collieries .. 2.9, 3.4, 2.1, 2.5, 2.5.

Medium incidence collieries .. 1.2, 1.3, 1.6.

Mols Al₂O₃ Low incidence collieries .. 1.9, 1.8, 1.8, 1.4, 1.7, 2.0, 1.8, 1.8, 2.5, 2.5.

* Not included in the Medical Survey. The incidences quoted are those of certified silicosis.

When calculating the mineralogical compositions which are given in Table XCI, the same assumptions have been made as described on page 175, except that in samples A.2, A.5, A.6, S.4, where the X-ray diffraction data had shown quartz as either low, medium-low or medium, this has been taken to correspond to 5, 10 and 15 per cent. of quartz, respectively, in the total silicate minerals.

The amount of pyrite is small except in samples from A.3, A.6, A.9 and B.5. The occurrence of pyrite is to some extent sporadic and shows no regular variation with the change in the rank of the coal. The carbonates in the samples were shown by X-ray diffraction data (not reported in detail) to be ankerite or dolomite and siderite. As the exact composition of the mixed carbonates is unknown, the chemical data were calculated to calcium, magnesium and iron carbonates. In only two of the samples (S.3 and S.4) is the amount of iron carbonate high; in most of the other samples this is present to the extent of 6 per cent. or less.

Generally speaking, the amounts of calcium and magnesium carbonate increase with decrease in the rank of the coal, and in some of the bituminous coals they represent approximately 25 per cent. of the total minerals. Iron sulphate is reported as present in four of the samples, each of which also contains a high percentage of pyrite, the sulphate being an oxidation product.

In Table XCI, the illite, kaolin, quartz and alumina are expressed as percentages of the sum of these minerals. There is a greater variation in the quantity of illite in these samples than in those of the inherent mineral matter, where the illite is a minor constituent. It is difficult to make any generalisation from these results, but the samples from the bituminous coals tend to have more kaolin and less illite than those from the anthracite. The sample from colliery B.6, with a high incidence of certified silicosis, where the seam mined is at the base of the Pennant and has a sandstone roof, is an exception; it contains 83 per cent. of illite, as compared with 3-49 per cent. in the samples from the other bituminous collieries.

TABLE XC
Extraneous mineral matter.
(Minerals as per cent. of total minerals)

Colliery :	A.1.	A.2.	A.3.	A.5.	A.6.	A.7.	A.8.	A.9.	S.3.	S.4.	B.1.	B.2.	B.3.	B.4.	B.5.	B.6.	B.7.	B.8.
Illite	33.1	16.7	10.1	15.9	12.7	8.1	10.7	18.7	6.6	6.9	25.3	11.9	12.8	1.9	9.2	23.0	7.5	7.8
Kaolin	24.1	42.8	14.7	9.0	2.6	19.6	22.7	13.2	21.5	8.3	21.5	16.8	20.2	55.2	27.2	4.6	26.5	22.4
Quartz	7.9	3.2	6.3	4.5	1.1	0.1	0.1	1.3	0.1	4.8	0.3	0.1	0.1	9.1	0.2	0.4	0.1	0.1
Al ₂ O ₃	Nil	5.3	Nil	6.9	1.6	7.9	7.4	Nil	3.7	2.7	4.8	5.0	3.1	2.4	1.0	Nil	2.2	2.0
Pyrite	0.5	1.6	24.2	14.7	43.0	0.7	4.1	33.6	0.3	0.5	0.3	0.1	0.2	3.8	17.0	47.7*	2.7	3.2
Iron carbonate ..	6.6	8.8	3.5	15.6	13.4	21.7	13.6	5.7	33.3	59.6	10.6	14.1	10.4	10.7	2.0	10.5	10.4	10.4
Calcium carbonate	10.9	8.4	7.6	11.9	11.0	22.7	22.4	5.7	16.6	2.0	14.5	29.6	29.4	5.0	19.1	14.6	28.9	32.0
Magnesium carbonate ..	6.9	6.1	5.8	7.7	8.2	14.1	12.3	3.6	13.4	10.8	12.2	19.0	19.5	6.1	13.8	9.0	18.9	19.7
Iron sulphate ..	Nil	Nil	17.1	Nil	5.1	Nil	Nil	15.8	Nil	Nil	Nil	Nil	Nil	Nil	8.1	Nil	Nil	Nil
Calcium sulphate	0.6	0.7	0.5	1.2	0.3	0.6	0.6	0.5	0.3	0.3	0.9	0.2	0.4	0.5	0.3	Nil	0.7	0.5
Apatite	1.7	3.6	4.0	11.3	0.9	3.4	2.1	1.2	3.2	3.6	8.1	2.9	3.6	4.5	0.9	0.4	1.7	1.3
Rutile	0.8	1.0	0.2	0.5	0.1	0.2	0.7	0.4	0.1	0.2	1.0	0.1	0.3	0.7	0.2	0.1	0.1	0.1
Fe ₂ O ₃ (unaccounted for) ..	5.7	0.4	5.8	0.3	Nil	0.3	2.1	0.1	Nil	Nil	Nil	Nil	Nil	Nil	1.0	Nil	Nil	Nil
Na ₂ O (unaccounted for)	1.3	1.4	0.2	0.6	0.1	0.8	1.2	0.2	0.8	0.2	0.5	0.3	0.2	0.3	Nil	0.2	0.1	0.5
Total ..	100.1	100.0	100.0	100.1	100.1	100.2	100.0	100.0	100.1	99.9	100.0	100.1	100.2	100.2	100.0	100.0	99.9	100.0
Total minerals, per cent. of "sinks 1.60" fraction ..	35.9	33.6	46.6	46.6	63.5	47.2	45.3	42.3	57.0	63.4	49.0	56.9	52.0	55.2	66.7	50.1	57.0	55.2

* Mainly pyrite.

TABLE XCI

Extraneous mineral matter.

(Minerals as per cent. of total minerals containing SiO_2 , Al_2O_3 , K_2O and Na_2O)

Incidence of pneumoconiosis :	H	L	H	L	H	M	M	H*	M	L	L/M	L	L	L*	L*	H*	L*	L*
Colliery :	A.1.	A.2.	A.3.	A.5.	A.6.	A.7.	A.8.	A.9.	S.3.	S.4.	B.1.	B.2.	B.3.	B.4.	B.5.	B.6.	B.7.	B.8.
Calculated from chemical analysis :																		
Kaolin	37	62	47	24	14	54	54	39	65	36	40	49	56	80	73	16	72	69
Illite	50	22	32	43	71	22	26	57	21	31	49	35	35	3	25	83	21	24
Quartz	11	4	20	12	5	Nil	Nil	4	Nil	21	Nil	Nil	Nil	13	Nil	1	Nil	Nil
Al_2O_3	Nil	8	Nil	19	9	22	17	Nil	11	12	9	14	9	3	3	Nil	6	6
Na_2O	2	2	1	2	1	2	3	1	3	1	1	1	1	Nil	Nil	1	Nil	2
X-ray Diffraction Analysis :																		
Kaolin	M	H	M	H/M	M/L	H	M	M	H	H/M	H	H	H	H	H	L	V.H.	H
Mica	M	Trace	M/L	M/L	M	V.L.	M	M/L	V.L.	Trace	M/L	Trace	Trace	Nil	V.L.	H	Nil	V.L.
Quartz	M/L	V.L.	H	M/L	L	Nil	Nil	M	V.L.	H	Nil	Trace	Nil	M	Nil	L	Nil	Nil
Kaolinite type	—	L/M	—	L	M	—	M	M	L	L	H	H	H	H	H	—	H	H
Halloysite type	M	H/M	M	M	L	—	M	M	L	M	L	L	Nil	L/M	Nil	—	—	Nil

V.H. = very high.

H = high.

H/M = high to medium.

M = medium.

M/L = medium to low.

L = low.

V.L. = very low.

* Not-included in the Medical Survey. The incidences are those of certified silicosis.

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Quartz is present in six of the eight anthracite but in only two of the ten non-anthracite samples—those from S.4 and B.4, the latter being the only sample to contain a medium percentage of quartz together with a high percentage of kaolin.

As with the inherent ash, there is some Al_2O_3 unaccounted for in the extraneous ash, but there is apparently no relationship between the rank of the coal and the amount of free alumina. This forms, on an average, 9.4 per cent. of the siliceous minerals in the anthracite samples and 7.3 per cent. in the non-anthracite samples (Table XCI). The difficulty of accounting for the soda in excess of that required for the illite, noted when discussing the inherent mineral matter, is present when rationalising the analyses of the extraneous ash.

To sum up: the anthracite samples tend to have more mica, less kaolin and less carbonates than the other coal samples. The kaolin is more of the halloysite type in the anthracites and of the kaolinite type in the non-anthracites. Quartz occurs mainly in the anthracites, and free alumina and unidentified minerals may be present in some of the samples from both the anthracite and non-anthracite collieries. There are large variations in the amount of iron, but these are not related to the rank of the coal.

The examination of the coal seam mineral matter reported above cannot be regarded as complete. The data in Tables LXXXVII and XCI show reasonable agreement between the relative amounts of mica, kaolin and quartz estimated from X-ray diffraction work and those calculated from the chemical analyses, but several of the X-ray mica estimates in Table XCI appear unduly low. There are no satisfactory data for the excess alumina and soda; the exact composition of the two types of kaolin found is not known, and the assumption that the mica in the samples has the illite composition is not confirmed by any experimental work. A more detailed mineralogical examination would be required to answer these questions.

THE MINERALOGICAL COMPOSITION OF THE ROOFS, CLODS, AND MINERAL MATTER IN THE COAL IN RELATION TO THE INCIDENCE OF PNEUMOKONIOSIS

The medical survey carried out by Hart and Aslett has shown that there is a gradual decrease in the incidence of pneumokoniosis with decrease in the rank of the coal, but that there are also mines with both high and low incidences within the anthracite field itself. In trying to correlate differences in the composition of the various strata with this variation in incidence of pulmonary disease, it is therefore necessary to search (a) for contrasts correlated with the rank of the coal and (b) for contrasts related to the incidence of lung changes, independent of the rank of the coal. Some of the contrasts, or lack of contrasts, under (a) have already been mentioned in the description of the mineralogical composition of the various strata. In the following paragraphs the results given previously are reviewed with regard mainly to the incidence of pneumokoniosis.

Roofs and Clods

The samples of roof and clod described in this report have been taken from anthracite collieries where the incidences of pulmonary disease are both high and low (A.1, A.3 and A.6—high, A.2 and A.5—low), from one steam coal colliery (S.4) where the incidence is low, and from two collieries mining bituminous coal (B.2 and B.3) where the incidence is also low.

It might be argued that the number of samples examined was too small to permit any safe conclusions; but, as a preliminary exploration to see if there are any marked contrasts in the chemical and mineralogical composition of the clod sand roofs above seams of different rank, the results are worthy of discussion in the light of the medical survey.

The two major constituents of the roofs and clods are illite and quartz, kaolin and carbonates being present in most of the samples in comparatively small amounts.

Considering first the main contrast between the bituminous collieries with a low incidence of pneumokoniosis (B.2 and B.3) and two anthracite collieries with a high incidence (A.3 and A.6), it is to be noted that the roofs at the former contain almost as much quartz as those at the latter—26.2 and 21.6 per cent., as compared with 31.2 and 27.2 per cent., respectively. The calculated percentages of quartz in the clods at B.2 and B.3 are 20.9 and 9.1, as compared with 8.0 and 17.1 at A.3 and 7.7 at A.6.

From this selection of results there is no general contrast in the percentages of quartz, or illite in the roofs and clods from the low-incidence bituminous collieries and those from the two high-incidence anthracite collieries.

A.1 is an anthracite colliery where the colliers show a high incidence of pneumokoniosis, and here the roof and the clod contain 45 and 24.5 per cent. of quartz, respectively. These are among the highest percentages of quartz found in any of the samples. A.2 is a nearby colliery, mining the same seam but where the incidence of lung disease is low, and the clod and the roof contain only 18.6 and 14.2 per cent. of quartz. A superficial observation might be made that the contrast in the percentages of quartz in the strata at these two collieries is sufficient to suggest an explanation of the differences in the incidence of pneumokoniosis, but if the A.1 samples are compared with the samples taken at A.5, which is a colliery where the incidence is low, it will be seen that the roof and clod of the latter contain as much quartz as at A.1; the two roof samples at A.5 contain 27 and 43.7 per cent. of quartz, and the two samples of clod 30.1 and 27.4 per cent. Taking the comparison a step further, it should be noted that the samples at A.5 (low incidence) contain on an average far more quartz than was found in samples from colliery A.6, mining the same seam but where the incidence is high.

The variations in quartz percentages of roofs and clods in relation to the rank of the coal and the incidence of pulmonary X-ray abnormalities in the colliers are shown in Fig. 15.

The data might suggest a slight decrease in the quartz content of the roofs with decreasing rank of the coal, but the evidence is not clear. Bearing in mind the limitations of the approach to the problem of the mineralogical composition of the roofs and clods described in this report, it would appear that there is no marked relationship between the amounts of quartz, illite and kaolin in the strata closely associated with the coal seam, and therefore handled by the collier, and the incidence of pneumokoniosis revealed by the medical survey. It should be borne in mind, however, that the methods used do not distinguish between primary and secondary quartz, nor do they make allowance for different amounts—or different composition—of an amorphous groundmass in the roofs and clods. These problems have been discussed in the petrological report (Brammall and Leech).

The sodium content of the illite decreases with decreasing rank of the coal. It is difficult to visualise any connection between this and the incidence of lung changes in the workers, but contrasting illite samples (fine fractions) are being tested in animals from this point of view.

Coalseam Mineral Matter.—Generally speaking, the total amount of mineral matter in the seams increases with decrease in rank, the anthracites being notably low in ash. The 18 seam samples selected for this study confirm this generalisation, which is based on a study of 238 seam pillar samples from different parts of the South Wales coalfield.

The inherent mineral matter consists chiefly of minerals of the kaolin group, similar to kaolinite and halloysite, with some illite and some free alumina. There are small differences between the various samples, the anthracite mineral matter being more of the halloysite and the non-anthracite more of the kaolinite type; but, apart from this, the inherent mineral matter is the same whether the coal is anthracite or bituminous, and its composition, as determined so far, would appear to be independent of the rank of the coal.

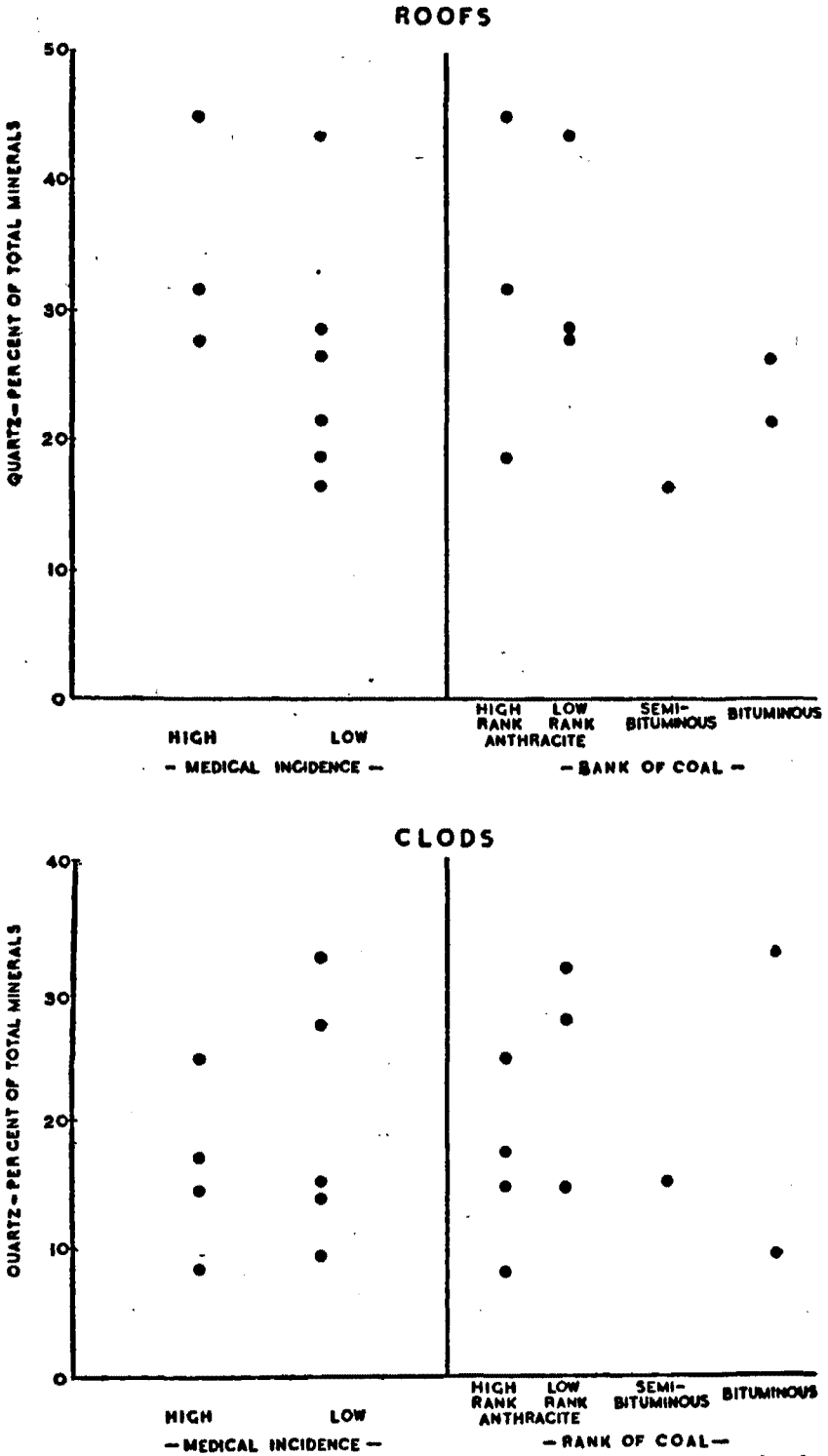


Fig. 15. Variations in quartz percentages of roofs and clods, in relation to rank of coal and incidence of pulmonary X-ray abnormalities in the colliers ("medical incidence").

The extraneous mineral matter is a very complex mixture; in addition to illite, quartz, kaolin and, in some instances, free alumina, it contains large amounts of carbonates (ankerite, dolomite, siderite) and, in some samples, a considerable quantity of pyrite.

The magnesium carbonate is always less than the calcium carbonate, and there is a fairly regular increase in the quantities of both as the rank of the coal decreases. Six out of eight anthracite samples, including those from the two low-incidence mines, contain quartz, as compared with two out of ten steam and bituminous samples. The bituminous samples contain, on an average, more kaolin as per cent. of the siliceous minerals than the anthracite ones, and the halloysite type is more marked in the anthracites, while the kaolinite type is dominant in the bituminous samples.

Free alumina, as per cent. of the siliceous minerals, bears no relation to the rank of the coal, but in an early stage of the inquiry it seemed to be absent from the extraneous mineral matter of high-incidence mines and present in that of low-incidence mines. This led to the examination of further samples, and the present total of 18 can be grouped into five from high, four from medium or low-medium, and nine from low-incidence mines, incidence here referring to pulmonary X-ray abnormalities amongst colliers at the mines surveyed by the medical investigators and to certified silicosis at the others, as indicated in Tables LXX, LXXXIX and XCI. The average percentage of free alumina in the sum of the minerals containing SiO_2 , Al_2O_3 , K_2O and Na_2O (Table XCI) is 2 for high, 9 for low and 15 for medium incidence mines, and the corresponding figures for anthracite mines only are 2, 13 and 20. The medium incidence mines are out of line, and it must be admitted that there does not seem to be more than a possible hint of a relation between the occurrence of free alumina and the incidence of pneumokoniosis. These data are interesting, in view of the findings of other workers that aluminium, and to a lesser degree aluminium oxide and hydroxide, are capable of coating quartz particles and may thus reduce the quartz hazard in silicosis (Denny, Robson and Irwin, 1939). It must be remembered also that the existence of free alumina in the samples has not been proved by positive identifications, but is deduced from the chemical data, which show an excess of Al_2O_3 if the mineral content is calculated according to the findings of X-ray diffraction analysis.

The chief apparent contrasts which have been noted may be summarised as follows:—

(a) Anthracite and Non-Anthracite Collieries

	Anthracite.	Non-Anthracite.
Roofs and clods	More quartz in roofs (?). More Na_2O in illite.	Less quartz in roofs (?). Less Na_2O in illite.
Coalseam	Less ash (?).	More ash (?).
Inherent mineral matter ..	Kaolin more of halloysite type (?).	Kaolin more of kaolinite type (?).
Extraneous mineral matter ..	Quartz (?). More mica (?). Less kaolin (mainly of halloysite type). Less carbonates.	No quartz (?). Less mica (?). More kaolin (mainly of kaolinite type). More carbonates.

(b) Anthracite Collieries

	High incidence.	Medium incidence.	Low incidence.
Roofs and clods	No contrasts		
Coalseam	No contrasts		
Inherent mineral matter ..	No contrasts		
Extraneous mineral matter ..	More quartz (?). No free alumina (?).	No quartz Free alumina	Less quartz (?). Free alumina

Note : (?) indicates that most but not all samples show the effect indicated.

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(c) *All High and Low Incidence Collieries*

	<i>High incidence.</i>	<i>Low incidence.</i>
Roofs and clods	No contrast	
Coalseam	Less ash (?).	More ash (?).
Inherent mineral matter	No contrast	
Extraneous mineral matter	Quartz.	No quartz (?).
	No free alumina (?)	Free alumina.
	More mica (?)	Less mica (?).
	Halloysite type (?)	Kaolinite type (?).
	Less carbonate.	More carbonate (?).

Note : (?) indicates that most but not all samples show the effect indicated.

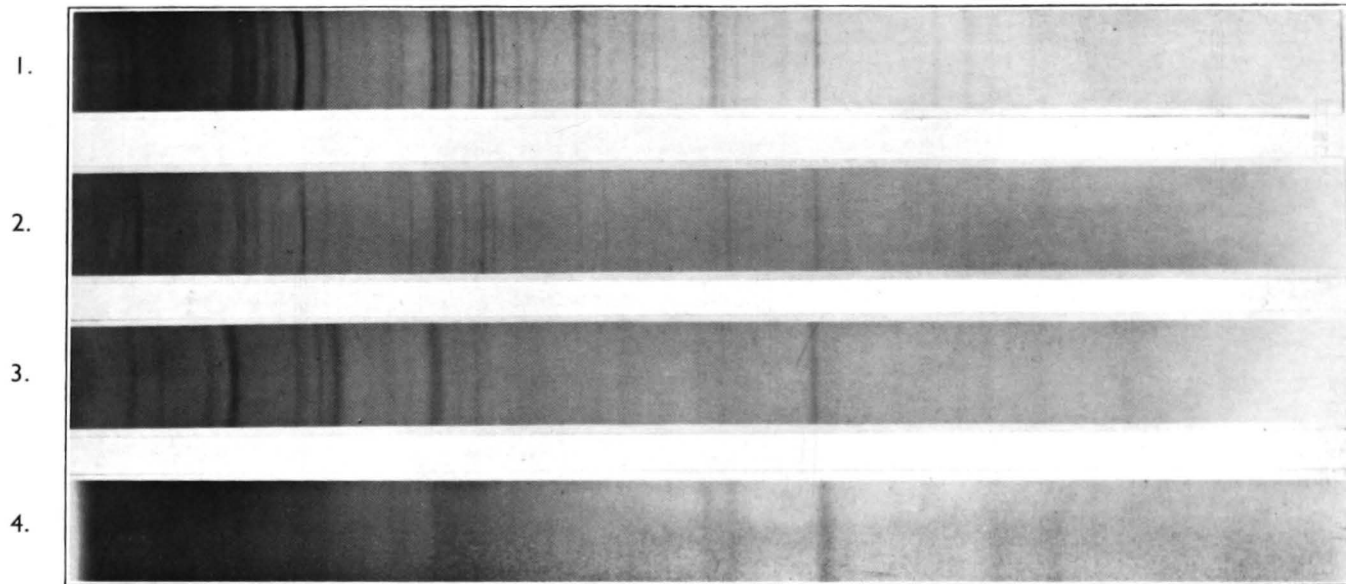
The data do not suggest that the variations in the incidence of lung changes described in the medical report are associated with differences in the bulk composition of the roofs and clods, as far as these were examined in this study. More striking than the contrasts are the similarities of the roof and clod samples, irrespective of rank of coal or incidence of lung disease, and the similarity of the inherent mineral matter of the different seams. The evidence relating to the extraneous coalseam mineral matter, on the other hand, suggests several contrasts. Many but not all of the samples from high-incidence mines contained quartz, whereas this mineral was found in samples from only two of the ten low-incidence mines. On an average, higher proportions of mica and the halloysite type of kaolin were present in samples from high-incidence mines, and less mica and the kaolinite type, with some free alumina, in samples from the low-incidence mines. X-ray powder diagrams of kaolinite and halloysite and of acid-treated 380° ash residues containing these minerals are shown in Plate F VIII. Preliminary results of animal injection experiments with halloysite by L. U. Gardner (1938) suggest that this mineral, although much less active than quartz, may not be innocuous.

In the assessment of the contrasts listed above, the data from the two medium-incidence anthracite mines, A.7 and A.8, are of particular interest. Here the men examined by the medical investigators had worked most of their lives in the Nine Feet seam. At both collieries this seam is thick; it has been worked chiefly by the pillar and stall method and the roof is not ripped, in fact, it is rarely ever handled by the collier. Also, there are no prominent nor persistent layers of clod separating the beds of coal. Furthermore, the extraneous mineral matter in the seam at these collieries contains no quartz, a comparatively low percentage of mica, a high percentage of kaolin and some free alumina. These findings are confirmed by the analysis of the air-borne dust at colliery A.8, which was found to contain only a trace of quartz. Thus the rock contributes only very little to the air-borne dust, and the mineral matter of the coalseam is very similar to that from low-incidence bituminous mines. In particular, quartz is absent and free alumina present. These data throw doubt on the relevance of the contrasts given above.

There are further difficulties in assessing the bearing of our data on the medical evidence. The grain-size distribution of the extraneous mineral matter has not been studied. It may include a certain proportion of large particles, which would contribute considerably to the analytical results, but might not be represented in air-borne dusts of respirable size. Further, there are no data to show the accessibility of the various components of the mineral matter dispersed in the coal on entering the lungs of human beings. Another factor which has not yet been studied is the hardness and dust-forming properties of the various roofs and clods. These, and the relative extent to which the roofs and clods are ripped in the collieries in question, will influence the total amount of respirable dust formed from mining them.

In view of these difficulties, it is not possible to estimate the importance of the contrasts described, without much further study, including animal experiments, but the data provide a basis for the selection of samples for such experiments.

PLATE F VIII



X-ray diffraction powder diagrams : 1 Kaolinite ; 2 Raolinite Type in coalseam mineral matter ;
3 Halloysite Type in coalseam mineral matter ; 4 Halloysite.

Our findings thus reveal no differences in the composition of the roof and clod samples which can be correlated with the incidence of disease in the workers, although the presence of a sandstone roof, as in colliery B.6, might, of course, present a special hazard in a given mine. Certain contrasts are, however, found in the composition of the extraneous mineral matter of the coal-seam, which might be related to the incidence of pneumokoniosis. For the reasons given above, the importance of these contrasts cannot at present be assessed. There remains one obvious difference related to the rank of the coal, and that is the coal material itself. It might be difficult to visualise differences in hazard due to coal alone, although such differences have recently been reported from animal experiments (Ravvin and Eniakov), but it seems possible that coal of various ranks can act differently in conjunction with the mineral matter with which it is associated. This suggests the need to study those physical and chemical properties of the coal which might have a bearing on the initial deposition of the coal dust in the lungs; such studies would include observations of the hardness and dust-forming properties of the various types of coal, the porosity and ease of wetting, and the ease with which fine suspensions of the various types of coal are flocculated. A correlation between the ease of flocculation of coal slurry and the rank of the coal has been found by Yancey *et al.* (1940). Animal experiments with ashless coal of different rank (or with coal of as low an ash content as it is possible to obtain) might give an indication as to whether the coal itself is an important factor in the causation of pneumokoniosis.

SUMMARY AND CONCLUSIONS

(1) The sources of the air-borne dusts in South Wales coal mines have been studied by chemical and X-ray diffraction analysis, and by calculation of the mineralogical composition, based on the analytical data.

Nine roof and ten clod samples, taken from eight of the 16 collieries covered by the medical survey, have been examined; they include samples from mines with high and low incidences of pulmonary disease.

The mineral matter in the coal has been divided into three fractions by gravity separation of the coal from seam pillar samples taken at 18 collieries. The ash of the lightest fraction is taken to represent the inherent mineral matter, and that of the heaviest fraction the extraneous mineral matter. The ash of four of the lighter fractions has not been analysed. The 18 collieries, 12 of which were included in the medical survey, are representative of the full range of South Wales coals; they are widely spaced geographically and include eight anthracite collieries with high and low incidences of pneumokoniosis, two steam coal collieries with medium and low incidence, and eight bituminous coal collieries, one with high (B.6), one with low/medium and eight with low incidence.

(2) The roofs and clods were found to contain mainly mica and quartz, with minor quantities of kaolin, carbonates and other minerals. The mica isolated from six samples was identified as illite. The quartz content of the roofs and clods varies from 8 to 46 per cent. of the total minerals, and the roofs tend to contain slightly more quartz than the clods.

The inherent mineral matter consists chiefly of minerals of the kaolin group, with some mica, carbonates and free alumina. The extraneous mineral matter contains the same minerals and, in some samples, quartz. The amounts of carbonates (ankerite-dolomite and siderite) are often large, and considerable amounts of pyrite (FeS_2) may occur.

(3) The variations in the composition of the samples are discussed in relation to differences in the rank of the coal, and in the incidence of pulmonary disease. In view of the comparatively small number of samples analysed, the results should be regarded as suggestive rather than conclusive.

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The quartz (and illite) content of the roof and clod samples shows no clear relation with rank or disease incidence, though the quartz content of the roofs may decrease slightly with decreasing rank (Fig. 15); the sodium content of the illite decreases (from 1.8 to 0.6 per cent.) with decreasing rank.

The kaolin in the inherent mineral matter is more of the halloysite type in the anthracite samples, and more of the kaolinite type in the others, but the inherent mineral matter shows no other contrasts. The extraneous mineral matter tends to have quartz, more mica, less kaolin and less carbonates in the anthracite samples (with kaolin more of the halloysite type), and no quartz, less mica, more kaolin and more carbonates in the non-anthracite samples (with kaolin more of the kaolinite type). Quartz tends to be present in samples from high-incidence and absent from samples from low-incidence mines, while the converse holds true for free alumina, which shows no relation to the rank of the coal (see Tables, p. 183-4).

Difficulties in assessing the significance of the contrasts observed are discussed and it is pointed out that more striking than the contrasts are the similarities of the samples, irrespective of the rank of the coal or the incidence of pulmonary disease. The need for a closer study of the coal material itself is stressed, in view of the possibility of a differential action in the lung of coal of different rank, either alone or in conjunction with the mineral matter with which it is associated.

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CHRONIC PULMONARY DISEASE IN SOUTH WALES COAL-MINERS. II.—ENVIRONMENTAL STUDIES

G.—NITROUS FUMES FROM SHOT-FIRING IN RELATION TO PULMONARY DISEASE

BY

J. IVON GRAHAM, M.A., M.Sc., F.I.C., F.R.C.Sc.I.,

AND

D. F. RUNNICLES, Ph.D., A.I.C.

(Mining Research Laboratory, British Colliery Owners Research Association, Royal School of Mines, London)

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INTRODUCTION

The fact that the consumption of explosive per ton of coal is nearly twice as high in the anthracite area as in the South Wales and Monmouthshire coal-mining area as a whole has led to the suggestion that the relatively large consumption of explosive in the anthracite coalfield may have a bearing upon the high incidence of chronic pulmonary disease in that area.

The fumes resulting from the firing of an explosive underground consist of finely divided particulate matter, either solid or liquid, together with the gases carbon monoxide, oxides of nitrogen, sulphuretted hydrogen and ammonia. The particulate matter, consisting in the main of preformed dust blown into the air by the force of the explosion, or of dust freshly produced by the latter, may possibly contain some of the solid constituents of the explosive.

Although carbon monoxide has frequently been responsible for cases of poisoning where ventilation has been insufficient, there is no evidence that chronic ill-effects follow repeated exposure to what must, on the average, amount to only a relatively very low concentration of this gas. The fumes from black powder give an appreciable amount of sulphuretted hydrogen, but with the explosives in use at the present time in the anthracite area there is little likelihood of this gas or of sulphur dioxide being formed. In the blasting of sulphur-bearing rock, a small quantity of sulphurous gases may possibly be produced, even with modern explosives, although no evidence of this has been obtained in the present study. The formation of ammonia has been noted, particularly with explosives containing a high percentage of ammonium nitrate, but, as will be seen later, the quantity found appears to be insufficient to produce any harmful results.

Nitrous fumes may consist of nitrous oxide, nitric oxide, nitrogen dioxide, nitrogen tetroxide and nitrous and nitric acids. Of these, the most important

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would appear to be nitrogen monoxide (NO), nitrogen dioxide (NO₂) and nitrogen tetroxide (N₂O₄). Mixtures of these gases will come into equilibrium in accordance with the reactions $2\text{NO} + \text{O}_2 \rightleftharpoons 2\text{NO}_2$ and $2\text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4$.

The former reaction is at ordinary temperature almost irreversible; with the pure gases, the second reaction at lung temperatures will give equilibrium when the ratio of NO₂:N₂O₄ is approximately 3:7. When, however, the concentration of nitrogen dioxide is very low, the change from N₂O₄ to NO₂ will be almost complete. This will undoubtedly be the case with the concentrations encountered underground.

Experts on explosives seem to agree that the oxide of nitrogen which predominates immediately after shot-firing is the monoxide (NO). Where, however, the explosion, instead of being completely detonated, undergoes partial burning, nitrogen dioxide is believed to be formed in relatively high proportion. Bodenstein and his colleagues (1918) showed that the rate of oxidation of nitrogen monoxide decreases with rise of temperature: with a low concentration of nitrogen monoxide in the absence of any catalyst, the rate of oxidation is extremely slow. At ordinary temperatures, with 10 parts per million of nitrogen monoxide the rate is such that approximately 10 per cent. is converted to the dioxide after 1 hour, 25 per cent. after 3½ hours and 50 per cent. after 10 hours. In the immediate vicinity of the shothole, however, the concentration of the oxides of nitrogen will probably be considerably higher than 10 parts per million, so that, on contact with the oxygen of the air, the initial rate of oxidation will be much greater than is indicated by this example. To what extent catalytic action occurs in presence of broken coal is not known, but this is being studied in the Mining Research Laboratory.

Nitrous and nitric acids may be formed as droplets if the atmosphere is damp. The physiological effect of these substances would appear to be similar to that of nitrogen dioxide, since the latter in reaching the lung will be converted to a mixture of the two acids: the decomposition of 1 mg. of nitrogen dioxide will yield 0·51 mg. of nitrous acid and 0·68 mg. of nitric acid. Neutralisation of these acids by the alkali in the tissues of the respiratory tract produces nitrite and nitrate in the form of sodium salts, and in this process an irritant action is caused. Sodium nitrite exerts a systemic action which, according to Henderson and Haggard (1927), is the same whether the salt is swallowed or produced from the inhalation of nitrous fumes. There is dilatation of the peripheral arteries, blood pressure falls, and headache and giddiness occur, whilst, in large amounts, nitrite alters haemoglobin to methaemoglobin. After exposure to high concentrations of nitrogen dioxide the irritation of the respiratory tract is so intense that it obscures the systemic action, and the latter does not play an important part in poisoning by nitrous fumes. Frequent exposure to low concentrations would seem to give an acquired habituation to sodium nitrite, which prevents the development of systemic effects but does not render the lungs less sensitive to irritation. Bulletin No. 272 of the U.S. Public Health Service, which has appeared since the commencement of this investigation, gives a helpful summary of the information at present available concerning the physiological and pathological actions of the different oxides of nitrogen.

The harmful action of nitrous fumes, probably consisting chiefly of nitrogen dioxide, has been recognised for many years, the first fatality, resulting from exposure to a high concentration of these gases, having been reported by Desgrange in 1804. Experiments have indicated that concentrations greater than 0·02 per cent. or 200 parts per million, are necessary to produce any acute effect in animals (rabbit or cat) exposed for a relatively short time. Lehmann and Hasegawa (1913) showed that 280 parts per million had no immediately toxic effect upon a rabbit exposed for 1 hour, but a cat exposed to 235 parts for 5½ hours died after a further 1¼ hours, whilst exposure to 230 p.p.m. for 7 hours

caused death in that time. Although there is a good deal of information as to the pathological and clinical effects of poisoning by nitrous fumes, little direct information is available concerning the action of particular concentrations of the oxides of nitrogen on man, the experiment of Lehmann and Hasegawa (1913) being probably the most illuminating. These are summarised in Table XCII. Nitrous fumes in relatively high concentration are the most insidious of all the irritant gases. A workman may be little inconvenienced after inhalation of the fumes and may go home from his employment and eat his supper feeling perfectly well. During the night oedema of the lungs may develop, and within 12 hours he may be dead, drowned in the volume of fluid poured out in his lungs. The concentrations of the fumes needed to cause these acute effects are, however, much higher than any likely to be experienced in coal mines.

TABLE XCII

Toxicity of nitrogen dioxide for man(Lehmann & Hasegawa, 1913, and *Publ. Hlth. Bull. Wash.*, No. 272, 1941)

<i>Concentration.</i>	<i>Symptoms (Experiments by Hasegawa on himself).</i>
60 parts per million	Moderate irritation of larynx, respiration slightly increased and shallow.
100 parts per million	Marked irritation of larynx, cough.
200 parts per million	Very marked irritation of nose and larynx, cough, increased nasal secretion and lachrymation.
	<i>(Lehmann's conclusions).</i>
40 parts per million	May be tolerated for several hours by many persons.
75 parts per million	May be tolerated for half an hour.
120-150 parts per million	Dangerous with somewhat prolonged exposure.
230-400 parts per million	Rapidly increasing danger.

In view of the probable harm resulting from even a relatively short exposure to nitrous fumes in quantity greater than 40 parts per million, expressed as nitrogen dioxide, it seemed possible that prolonged exposure to a much lower concentration might result in damage to the lungs or bronchi which might be responsible for harmful action of dust that normally would be harmless. In 1934, it was thought desirable by the late Professor J. S. Haldane and one of us to ascertain, in the first place, what concentrations of nitrous fumes were encountered in the Welsh anthracite pits. Since the majority of cases of chronic pulmonary disease in the anthracite area occur amongst the colliers, it is clear that any connection between fumes and pulmonary trouble must apply to the production of fumes at the coalface, and not alone to hard headings where ventilation is so restricted that an objectionably high percentage of fumes may result from shot-firing. With the help of Dr. T. D. Jones*, a series of tests, by means of snap samples, was made, to determine the amount of nitrous fumes produce during shot-firing at the coalface at four anthracite pits which showed a big difference in respect of silicosis claims. These results, which gave concentrations up to 90 parts per million, were published by the British Colliery Owners Research Association in a short report (Haldane & Graham, 1935), in which it was pointed out that exposure to the concentrations determined could be only for the space of a minute or so. Although, under the ventilation conditions in existence at these four pits, it was concluded that the tests had not disclosed any real danger from nitrous fumes, the need for good ventilation at the coal face was stressed. Subsequently, further investigation was made by the staff of the Mining Research Laboratory, with particular

* Now Professor of Mining, University College, Cardiff.

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reference to the production of nitrous fumes in hard headings, and much useful information was obtained regarding the quantity of nitrous fumes formed, and also in regard to the suppression of fumes by means of a mist of water or sodium carbonate solution.

In 1934, a very interesting paper was published by Robson, Irwin and King, describing experimental work carried out at the Banting Institute, Toronto, on the effect upon rabbits of nitrogen dioxide either in conjunction with silica dust or alone. It was claimed by these investigators that rabbits which had been exposed to atmospheres containing as little as 0.01 per cent. (100 p.p.m.) by volume of nitrogen dioxide for two hours per diem along with fine silica dust in some cases showed characteristic silicosis after 12 or 13 weeks, whilst under comparable conditions with silica dust alone the time for development of silicosis was 10–11 months. Concentrations of nitrogen dioxide which are definitely objectionable from the point of view of producing acute poisoning are occasionally encountered after shot-firing in places where the ventilation is very poor. Normally, the amount of nitrogen dioxide in the atmosphere after shot-firing, and particularly on a long wall face, is well below this figure. It seemed possible, however, in view of the experiments at the Banting Institute, that if concentrations even much less than those required to produce acute poisoning prevailed in the workings of the anthracite collieries, they might be conducive to the development of chronic bronchial trouble, which, in turn, might facilitate the production of silicosis.

When the Committee on Industrial Pulmonary Disease began their investigations, it was thought desirable that a more complete survey should be made in regard to the production of nitrous fumes in the anthracite pits, and the Mining Research Laboratory, with its staff under grant from the Safety in Mines Research Board, was asked to undertake this work.

The results obtained in the earlier investigations were all from "spot" tests, which were not, on the whole, very numerous so far as the anthracite workings were concerned. It was thought that any action producing effects of a "chronic" type would probably depend upon the average concentration of fumes to which the miner was exposed during the course of his work, and tests from this point of view were carried out in mines where clinical and X-ray observations of the workers, and various other environmental studies, were being made for the Committee. The pits at which these tests were carried out varied considerably in their incidence of silicosis and as regards environmental conditions.

Going from West to East (Anthracite—high rank—lower rank—Steam—Bituminous) these mines were:—

A.1.	Anthracite—High Rank	A.5	Anthracite—Lower Rank
A.2.	"	A.6.	"
A.3.	"	A.7.	"
A.4.	"	A.8.	"
A.X.	"	S.4.	+ Steam
A.9.	"	B.3	+ Bituminous

Details as to the methods of working in these mines have been given in the medical survey (*Special Reports Series*, No. 243, Table VI, pp. 43 and 44).

For comparative purposes, measurements were also made in hard headings in two other collieries, one in Kent and the other in Somerset.

SAMPLING OF NITROUS FUMES

The explosives used were all of the type permitted for use in safety lamp pits, and no evidence was obtained of the presence of any appreciable quantity of sulphur dioxide, hydrogen sulphide or hydrogen cyanide. The approximate compositions of some of the explosives employed during the tests are given in Table XCIII.

TABLE XCIII
*Percentage of the principal ingredients of explosives used during the investigations**

	<i>Polar Dynobel.</i>	<i>Polar Ajax.</i>	<i>Polar Samsonite No. 3.</i>	<i>Polar Saxonite.</i>	<i>Polar Viking.</i>	<i>Polar Dynobel No. 2.</i>	<i>Polar Saxonite No. 3.</i>
Nitrated mixture of glycerine and ethylene glycol	14-16	} 28.5-30.5 {	57-59	24-26	8-11	} 12-14	29.5-31.5
	0.25-0.75		2.5-4.5	—	—		—
Nitro cotton	0.250.75	0.25-1.0	—	0.25-1	—	—	—
Tri-nitro-toluol }	0.5-1.5	0.5-2.5	—	1-3	—	—	1-3
Di-nitro-toluol }							
Ammonium nitrate	51-54	38-40.5	—	35-38	70-73	65.5-68.5	30.5-33.5
Sodium chloride	24-26	24-25	11.5-12.5	32.5-34.5	8-10	9.5-11.5	29-31
Sodium nitrate	—	—	2.5-5.0	—	1-3	—	—
Borax	—	—	23	—	—	—	—
China clay	—	0.5-5.5	—	—	0.5-2	1-2	—
Wheat flour (dry)	—	0.5-3.5	—	—	—	1-3	—
Woodmeal (dried at 100° C.)	4-6	—	—	0.5-1.5	7-9	4.75-6.75	0.5-1.5
Moisture	2	2	2	2	2	2	2

* Information obtained from H.M. Mines Department and from particulars supplied with explosives.

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In order to achieve a fair comparison between the selected collieries, in regard to the production of nitrous fumes, an average value of the fume concentration was obtained, by carrying out the measurements over relatively long periods, so as to minimise the effect of daily variations in shot-firing intensity. This was done by sampling the mine air continuously over a period of from one to four weeks by means of an aspirator. The average of successive determinations, made in this way, is believed to give a suitable figure for purposes of comparison. The underground districts selected for the tests were chosen so as to be representative of normal working conditions, and in most cases were the same as those in which other environmental studies for the Committee were carried out. We are indebted to the management of each colliery for the information concerning number of shots fired, weight of explosive, number of men employed in the districts studied, and tonnage of coal. The sampling apparatus was placed in the return air from the district under investigation, as near as possible to the last working place, so as to collect the fumes from all the shots fired in the district. In view of the prolonged period of the test, this site for the apparatus was preferred to a position on the face itself, since it involved less risk of damage to the apparatus; furthermore, it was felt that the data obtained from this position would give a better average for the production of fumes in the district. In most cases the quantity of air found at the point of sampling in the return airway was greater than that in the first working place, owing to leakage short-circuiting from the intake airway, but, on the other hand, the air had collected all the fumes, and the concentrations are probably not very different from that at the end of the first stall. At the commencement of this investigation, the air was sampled continuously over the 24 hours; later, it was sampled for one shift only per day, usually on the coal-getting shift, which was the subject of most attention in the environmental investigation.

The aspirator consisted of two Winchester quart bottles, graduated in 100 c.c. intervals, from which the water was syphoned out through a rubber tube leading to a glass capillary; the diameter of the latter was about 0.5 mm., and the length was adjusted so that the contents of the bottles, 5,000 c.c., could be emptied over any period up to a month. The water was syphoned under a constant head of pressure, and the air entering the bottles was first drawn through a series of vessels in which the nitrous fumes were absorbed. The graduations on the bottles gave the total volume of air sampled, and the amount of nitrous fumes in the absorbent was subsequently estimated in the laboratory. The whole apparatus was contained in a wooden box, closed except for a small hole, through which the air inlet tube projected. Plate G IX, Fig. A, illustrates the apparatus in position underground.

The air inlet tube originally consisted of about 6 in. of 2 mm. bore glass tubing, one end dipping below the absorbent in the first vessel of the absorption train. With tubing of this bore, it was found that the nitrous fumes passed along the tube to the absorbent by diffusion, and also as a result of the slight pumping action due to fluctuations in barometric pressure, at a rate comparable with the slow rate of aspiration (10 c.c. an hour), giving an erroneously high result. This error was minimised by reducing the bore of the inlet tube to 0.4 mm. Several blank experiments in which a closed absorption vessel, with tube dipping into the absorbent, was left underground for a long period, proved that no appreciable amount of nitrous fumes passed into the absorbent along this narrow bore tubing.

The aspirator ran continuously without any attention. After a week or more, when sufficient air had been drawn through the vessels, the absorbent was changed and the aspirator bottles refilled. Distilled or boiled water was used for the aspirator bottles, to avoid any possible blockage in the outlet capillary tube. For the measurements that were made during one shift per diem, a tap, operated from outside the box, was fitted to the water-outlet. This

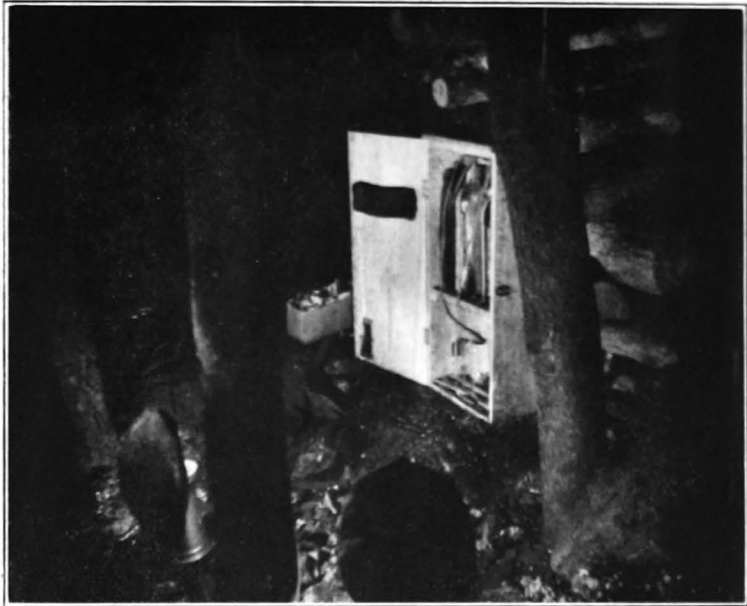


FIG. A. Syphon aspirator in position underground, for estimating the average concentration of nitrous fumes over 24 hours.

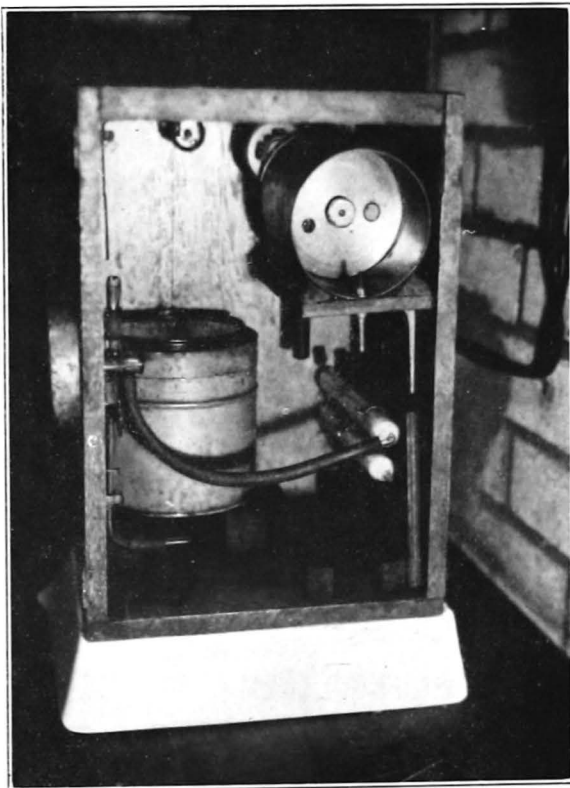


FIG. B. Clockwork-driven aspirator, for estimating the average production of nitrous fumes during the working shift.

enabled a colliery official to set the aspirator in operation for the period of the shift.

Another form of aspirator was constructed, in which the period of sampling of the air each day could be pre-set, and the equipment thus allowed to operate automatically over long periods. In this aspirator the air was drawn through the absorption vessels by the lifting of a metal bell floating on the surface of water in a container; the action is the reverse of that in a water-gasometer, where the bell is forced up by the gas. The bell was raised by a thread attached to a clockwork-driven axle. The motive power was a clockwork barograph drum, mounted horizontally. The centre spindle rotated once in 24 hours, and carried a large gear wheel, which had two-thirds of its number of teeth filed off. This partially-toothed wheel was meshed with a smaller gear wheel, which wound up the thread attached to the metal bell. The two gears were set so that the toothed portion of the larger wheel drove the smaller one during the period for which it was desired that the air should be sampled. During this period the bell was being raised, and air drawn through the absorption train. Subsequently the toothed portion became disengaged, allowing the smaller gear wheel to slip and the bell to sink under its own weight; the bell was then ready to be raised the next day, when the toothed portion of the larger gear wheel again became engaged. The period of sampling was obviously determined by the number of teeth left on the large wheel; with two-thirds of the teeth removed the period was between $5\frac{1}{2}$ and 6 hours, this being approximately equivalent to the actual working time at the coal face. The air bell had a capacity of 800 c.c., so that sufficient air for an accurate nitrous fume measurement could be aspirated in a few days. The absorption train was duplicated, and, by changing the air inlet tube, a second test could be made without necessitating a further visit to the colliery. This apparatus, although more complicated than that previously described, was found to work very satisfactorily underground; it is illustrated in Plate G IX, Fig. B.

In addition to measurements of the average concentration of nitrous fumes underground, it was considered desirable to determine the concentrations of these fumes produced in the vicinity of a shot immediately after firing. This was done by taking a series of spot samples, the frequency with which they were taken depending on the velocity of the ventilating air current and resultant dispersal of the fumes. When the air velocity is high, as on a narrow coalface, the peak concentrations last only a very short time, and the spot samples have to be taken very rapidly to enable the changes in concentration to be followed. For this purpose, a number of 600 c.c. glass bottles was used. The bottles were 5 cm. in diameter and about 25 cm. long, narrowing down at one end to a length of 7 mm. tubing, which was sealed off in the flame after the bottle had been evacuated. A small quantity of absorbent solution was placed in each bottle before evacuation. The bottles were carried underground in long flat wooden boxes, each holding 24 in separate vertical compartments. By sliding the bottles half-way out of their compartments before the test, a series of samples could be taken at intervals of a few seconds, the sealed off necks being broken with a pair of pliers. The bottles were sealed with rubber caps and labelled at the end of the test.

ABSORPTION AND ESTIMATION OF NITROUS FUMES

It has already been pointed out that the main constituents of nitrous fumes are nitrogen monoxide (NO), nitrogen dioxide (NO_2) and nitrogen tetroxide (N_2O_4). The solution of the two latter gases in water contains nitrous acid (HNO_2) and nitric acid (HNO_3), the relative amount of each depending upon the proportion of dioxide and tetroxide in the nitrous fumes. For the purposes of estimation, it was decided to determine all the oxides together as nitric acid; it was therefore necessary to oxidize the nitrous acid. Hydrogen peroxide was

used as the oxidizing agent. The oxidation of nitrogen monoxide and the absorption of nitrogen dioxide in aqueous solution have been studied by Francis and Parsons (1925). They found that it is difficult to attain complete oxidation and absorption when the gases are mixed with air and passed through an aqueous absorbent. At a rate of 100 c.c./min. the amounts absorbed in aqueous solutions of acid hydrogen peroxide, alkaline peroxide, neutral peroxide and 50 per cent, potassium hydroxide are respectively, 28, 24, 18 and 60 per cent. The concentration of the nitrogen monoxide used in these experiments was between 20 and 30 parts per million. Tests in the Mining Research Laboratory, however, showed that with concentrations of the order of 10 parts per million, and at the same rate of flow, practically complete absorption could be obtained in 20 per cent. sodium hydroxide, with only one simple absorption vessel. Although 20 per cent. sodium hydroxide is satisfactory as an absorbent with the rate of flow and concentrations of nitrous fumes encountered in this investigation, it was not generally used, since the presence of a large amount of alkali inhibited the oxidation to nitrate by hydrogen peroxide and also seriously handicapped the accuracy of the subsequent analysis of the nitrate. The absorbent used was 10 vol. hydrogen peroxide, acidified to $\frac{N}{50}$ with sulphuric acid.

In this medium the oxidation to nitric acid is very rapid. The absorption of nitrous fumes, however, is much slower, and even at the slow rates of aspiration used in the measurements underground, an improved form of absorbing vessel, which gave a longer time of contact of the gas with the absorbent, had to be used. This was effected by using a long tube inclined at about 10° to the horizontal, in which the gas bubbles slowly rose. The long tube was found to be rather fragile for use underground, and was later replaced by a glass tube of about 12 mm. bore and 15 cm. long, filled with 5 g. of glass wool. This gives a large absorbing surface with only a small quantity (8-10 c.c.) of absorbent, and requires practically no pressure head for the passage of gas. An absorbing vessel of this type was essential for use with the clock-work driven aspirator, as the air had to pass both ways through the vessel, with little or no pressure head.

The results of tests carried out in the laboratory with definite concentrations of nitrogen dioxide are shown in Table XCIV below. The NO_2 was prepared by the addition of definite quantities of NO to the air stream, on the assumption that the greater portion of the NO would be oxidized to NO_2 before passage through the acid peroxide solution used as the absorbent; in practice, it is possible that some of the NO was not oxidized, especially in the case of a high rate of flow.

The usual rate of aspiration of the mine air through the absorbing vessels varied from 2.5 to 0.15 c.c. per minute, so that it may be assumed that the quantity of oxides of nitrogen not absorbed was well within the limits of experimental error. In the later stages of the investigation, the two bubblers were dispensed with, and two glass-wool tubes in series were used. These tubes were easily filled by drawing 20 c.c. of absorbent through in three portions. On blowing out the excess, 8-10 c.c. were retained on the glass wool. The tubes were emptied by drawing about 60-70 c.c. of water through them in four portions. The exact amount of hydrogen peroxide in the absorbent must be determined. This was done by titrating the acid present in the absorbent, using an external methyl orange indicator.

It should be made clear that, unless otherwise stated, the results given in this report are for total oxides of nitrogen expressed as NO_2 . No attempt was made to differentiate between the various oxides of nitrogen. The most convenient method for the determination of nitrogen dioxide is by means of the Greiss-Ilosvay reagent. The method depends upon the development of a colour, which is not permanent, and it is therefore unsuitable for determining average

TABLE XCIV

Absorption train.	Rate c.c./min. gas flow.	Per cent. absorbed.	Per cent. distribution of absorbed nitrous fumes in absorption vessel.		
			1.	2.	3.
(a) 10 p.p.m. nitrogen dioxide :					
1. Bubbler ..	1.5	105	30	60	10
2. Long inclined tube	1.7	100	36	57	7
3. Bubbler ..	30	95	20	70	10
	30	107	19	65	16
	35	100	20	60	20
	40	80	13	80	7
	150	75	33	45	28
(b) 14 p.p.m. nitrogen dioxide :					
1. Bubbler ..	55	80	15	18	67
2. Bubbler ..	53	109	19	13	68
3. Tube with glass wool					
(c) 40 p.p.m. nitrogen dioxide :					
1. Bubbler ..	120	95	21	21	58
2. Bubbler ..	130	106	19	19	62
3. Tube with glass wool					
(d) 10 p.p.m. nitrogen dioxide :					
1. Bubbler ..	50	80	29	68	3
2. Tube with glass wool	41	80	28	65	7
3. Bubbler ..					

volumes over a long period. Spot tests were on occasion carried out for nitrogen dioxide by this method during individual shot-firing tests.

The phenoldisulphonic acid method, as used in water analysis, was found to be most satisfactory for analysing the nitrate in these investigations. The acid hydrogen peroxide absorbent, containing the absorbed nitrous fumes as nitric acid, was made alkaline with sodium hydroxide, and evaporated to dryness on a steam bath. Two c.c. of a solution of phenoldisulphonic acid in concentrated sulphuric acid were added to the dry residue. On diluting and adding ammonia till the mixture was alkaline, an intense yellow colour was produced, which was compared with glass standards in a Lovibond Nessleriser. These standard glasses had been matched by the makers with known standards prepared in the laboratory, and covered the range 0.002 to 0.015 c.c. of nitrogen dioxide. By adjusting the height of the column of the unknown solution in the Nessler tubes, the nitrous fumes in the sample could be determined to 0.0005 c.c. The standard test for nitrates for use with the Lovibond Nessleriser colour glass is with 2:4-xylene; it is no less sensitive than the phenoldisulphonic acid method, but is not so easily adapted for analysing a large number of samples, as it involves a steam distillation. The chief objection, however, is that the test is seriously interfered with by the presence of hydrogen peroxide.

Hydrogen peroxide, 20 vol. A.R. (British Drug Houses, Ltd.) was used in making up the absorbent, which usually contained from 0.0015 to 0.002 c.c. of nitrogen dioxide per 10 c.c. The blank of the absorbent usually represented about 10 per cent. of the total amount of NO_2 absorbed. It could, however, be determined fairly accurately by carrying out a nitrate determination on several 30 c.c. samples of the absorbent.

Some measurements were made by absorbing the nitrous fumes in aqueous sodium hydroxide and estimating the nitrite with the Griess-Ilosvay reagent. This test for nitrite is about 10 times as sensitive as the phenoldisulphonic acid test for nitrate, and it can be more rapidly performed. The accuracy of the Griess-Ilosvay reaction depends upon knowledge of the ratio of nitrous to nitric acid produced by the solution of the oxides of nitrogen in caustic soda. The results of a limited number of comparative measurements indicate

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TABLE

Average values for nitrous fumes from shot-firing obtained over 24 hours at of shots fired and amount

Colliery.	District.	Seam.	Length of face. Yards.	Output. Tons per diem.	Colliers per diem.	Non-colliers.	*Ventilation. c.f.m.	Height at face. ft. in.	Explosive used.
A.3 ...	a	Stanlyd ...	370	260	88	69	14,500	6 0	Polar Dynobel
A.3 ...	b	Stanlyd ...	50	30	14	16	2,000	6 0	Polar Dynobel
A.6 ...	a	Red Vein ...	670	370	97	132	10,000	4 6	Polar Samsonite Some Polar Dynobel
A.9 ...	a	Lower Pumpquart	300	140	38	37	7,000	4 0	Polar Dynobel 2
A.9 ...	b	Lower Triquart ...	240	80	26	25	7,000	3 0	Polar Dynobel 2
A.2 ...	a	Lower Pumpquart	350	150	76	62	9,000	7	Polar Dynobel Some Polar Ajax
A.2 ...	b	Lower Pumpquart	260	80	40	21	4,000	3 7	Polar Dynobel Some Polar Ajax
A.7 ...	a	Three Feet ...	980	260	138	88	3,200	3 1	Polar Dynobel Some Polar Ajax
A.7 ...	b	Eighteen Feet ...	1,070	150	55	35	5,600	11 3	Polar Dynobel
A.4 ...	a	Upper Pumpquart	150	60	28	11	3,000	4 6	Polar Dynobel
A.4 ...	b ^a	Stanlyd ...	200	120	48	25	8,000	4 6	Polar Dynobel
A.8 ...	a	Yard ...	180	34	56	9	7,500	2 8	Polar Dynobel
A.8 ...	b	Yard ...	90	81	41	12	4,500	2 8	Polar Dynobel
S.4 ...	a	Two Feet Nine ...	950	250	110	94	28,000	...	Polar Viking
S.4 ...	b	Three Feet Ten ...	440	150	54	38	20,000	5 0	Polar Viking
A.3 ...	Semi-hard heading.	Stanlyd ...	...	coal 2-2 rock 9-0	...	5	1,000	6 6	Polar Dynobel
K.X ...	Hard heading.	—	...	rock 13	0	9	2,500	9 0	Polar Saxonite

* Mostly figures supplied by colliery for ventilation of the district.

TABLE

Average values for nitrous fumes from shot-firing obtained over working number of shots fired and

Colliery.	District.	Seam.	Length of face. Yards.	Output. Tons per diem.	Colliers per diem.	Non-colliers.	Ventilation c.f.m.	Height at face. ft. in.	Explosive used.
A.1 ...	a	Lower Pumpquart	80	22	7	0	1,000	3 6	Polar Ajax Polar Dynobel
A.3 ...	a	Stanlyd ...	370	290	78	17	15,000	6 0	Polar Dynobel
A.2 ...	a	Lower Pumpquart	250	100	42	21	4,500	3 7	Polar Dynobel
A.5 ...	a	Red Vein ...	480	200	98	26	5,600	4 0	Polar Ajax
S.4 ...	a	Three Feet Ten ...	650	210*	D62 A 2 N18 D59 A24 N 0	21 10 14 5 4 12	21,600	5 0	Polar Viking
B.3 ...	a	Old Coal ...	510	120	A	10	10,800	5 1	Polar Dynobel
A.1 ...	Hard heading.	—	—	rock 14.4*	A	10	2,500	6 0	Polar Ajax
A.X ...	Hard heading.	—	—	4.4*	A	5	1,000	6 6	Polar Ajax

D = day shift; A = afternoon shift; N = night shift.

NITROUS FUMES FROM SHOT-FIRING

XCV

various collieries, together with information concerning ventilation, number of explosive used

Shot-firing. **Upper figures—Coal †Lower figures—Rippings.				Average temperature at face.	Relative humidity	Average nitrous fumes as NO ₂ p.p.m.	Observed incidence of X-ray abnormalities ("consolidations") amongst coalface workers, as percentage of expected value.‡	Remarks.
Per day.		Per ton.						
Oz.	No.	Oz.	No.					
**c	29	5.9	0.11	0.02	69.7	86	172	†At return of face.
†r	48	6.7	0.19	0.03				
c	18	3.0	0.60	0.10	59†	79	3.2	
r	16	2.0	0.53	0.07				
c	16	2.1	0.05	0.01	67	—	1.9	176
r	127	13.2	0.40	0.04				
c	290	71.0	2.07	0.51	—	—	2.8	—
r	40	9.0	0.29	0.07				
c	658	86.0	8.20	1.07	—	—	4.9	—
r	31	1.7	0.39	0.02				
c	755	101.0	5.05	0.68	59.8	90	2.0	12
r	116	12.0	0.77	0.08				
c	284	45.0	3.55	0.56	66.3	96	1.2	
r	22	3.7	0.27	0.05				
c	334	82.0	1.27	0.31	72.3	83††	0.8	95
r	217	25.0	0.83	0.10				
c	215	42.0	1.36	0.27	64.2	81††	1.4	††Winter observations, NO ₂ measured in summer.
r	0	0	—	—				
c	27	3.3	0.46	0.06	66.3	91	2.6	55
r	79	6.0	1.31	0.10				
c	12	1.6	0.10	0.01	68.1	96	4.5	
r	21	3.8	0.18	0.03				
c	13	4.3	0.37	0.13	68.8	81	2.0	146
r	67	7.3	1.96	0.21				
c	5.4	1.9	0.07	0.02	73.1	72	1.8	
r	51	4.5	0.63	0.06				
c	0	0	—	—	—	—	1.2	12
r	44	3.6	0.18	0.01				
c	0	0	—	—	—	—	1.2	
r	77	4.9	0.37	0.02				
c	15	3.0	6.80	1.36	—	—	3.0	—
r	4	0.3	0.45	0.03				
c	0	0	Rock.	Rock.	68.5	—	5.1	—
r	236	10	18.2	0.77				

‡ See footnote on p. 2.

XCVI

shift at various collieries, together with information concerning ventilation, amount of explosive used

Shot-firing. **Upper figures—Coal †Lower figures—Rippings.				Average temperature at face.	Relative humidity	Average nitrous fumes as NO ₂ p.p.m.	Observed incidence of X-ray abnormalities ("consolidations") amongst coalface workers, as percentage of expected value.‡	Remarks.	
Per day.		Per ton.							
Oz.	No.	Oz.	No.						
**c	56	5.8	2.50	0.26	72.7	70	2.3	233	Measured on day shift. District idle on two other shifts.
†r	11	1.3	0.50	0.06					
c	55	11.0	0.24	0.05	70.7	83	4.1	172	Measured on day shift.
r	11	1.7	0.05	0.01					
c	263	42.0	3.30	0.53	66.8	96	2.5	12	Measured on day shift.
r	29	5.7	0.37	0.07					
c	360	114	1.81	0.57	67.1	96	4.9	0	Measured on day shift.
r	110	13	0.55	0.06					
c	0	0	—	—	77	67	2.1	12	Measured on afternoon shift. Firing only afternoon shift. *Per 24 hours †Per ton per 24 hours.
r	79	5.2	0.38†	0.03	(return)				
c	0	0	—	—	—	—	3.1	4	Measured on day shift. Firing on night shift.
r	40	3.8	0.33	0.03					
c	0	0	—	—	—	—	5.0	—	Measured on 3 shifts of 5½ hours. *Per 3 shifts.
r	222*	12.5	15.40	0.87					
c	0	0	—	—	59	91	6.4	—	Measured on 2 shifts of 7½ hours. *Per 2 shifts.
r	300*	13	63.60	2.86					

‡ See footnote on p. 2.

that with nitrous fumes produced underground, this ratio is not constant. The less sensitive phenoldisulphonic acid method seemed therefore to be the more reliable for these investigations.

The results of the continuous tests are collected in Tables XCV-XCVIII. Tables XCVI and XCVIII give the details of individual tests from which the average figures recorded in Tables XCV and XCVII, for NO_2 production, have been deduced.

Study of the results in Table XCV shows that the average production of nitrous fumes at the return end of the face is of the order of a few parts per million—the figures lying between 0·8 and 5·1. There does not seem to be any direct relation between the type of explosive used and the average amount of fume. With the most popular explosive, polar dynobel, by itself, the figures vary between 1·4 and 4·9 parts per million. Moreover, it does not seem reasonable to expect that there should be any such relation, bearing in mind the great importance of correct charging of the shot-hole. In general, it was observed that ripping shots in stone gave a rather lower quantity of fume than was the case with shots in coal, no doubt owing to more efficient charging. In other words, the results indicate that there is a tendency when firing in coal to use more explosive than is necessary. Figures for the weight of explosive used per ton of coal give some idea of the exposure of colliers to fumes, but do not, of course, give any real indication of the relative quantities of fumes they are likely to inhale; and although the tests showed that the highest average figure for nitrous fumes (in parts per million) was obtained in the workings of a pit using the largest quantity of explosive per ton of coal mined, this relation has not been found to hold good in respect of other collieries. For example, at colliery A.2, where the total explosive used amounted in one district to 5·82 oz. per ton of coal mined, the average nitrogen dioxide was 2 parts per million. The workings in this colliery are definitely damp, which may explain the relatively low production of nitrous fumes. High humidity of the air in the workings will probably not be so effective in reducing the fumes as dampness of the coal or rock. At colliery A.8, where the workings are dry and the air humidity 72–80 per cent., the NO_2 production varies from 0·7 to 2·3 parts per million, with averages for two districts of 1·8 and 2·0, respectively. Obviously, the quantity of air passing along the face is a very important factor in the rate of removal of fumes, and the results given in Table XCV for samples taken in the return airway may not reproduce the exact conditions in the working places. On the other hand, the figures obtained for the NO_2 production may include nitrate from sources other than the firing of explosives, or the quantity of NO_2 formed actually from the nitrogen of the air during an explosion may be an appreciable factor. This may be deduced from the fact that the total production of NO_2 during 24 hours is in some cases greater than that possible were all the nitrogen of the explosive converted to NO —which is subsequently oxidized to NO_2 . The figures in Table XCV must therefore be taken as maxima. Table XCVII records the individual tests from which the average figures for NO_2 given in table XCV have been calculated. It will be seen from these data that, except in one or two collieries, the results of individual tests over periods of 7 to 64 days did not vary markedly.

As mentioned on p. 192, a number of tests were undertaken to determine the average concentrations to which men would be exposed in the working shift during which the firing was in most cases carried out. The results of these are given in Table XCVI. It will be seen that, contrary to what might be expected, the results obtained are not three times those for the 24 hours. This is intelligible when it is realised how readily the fumes may be absorbed by the coal and dust lying along the coal face. This absorption and slow emission of the fumes in a current of air has been noticed on numerous occasions; tests made

TABLE XCVII

Values for individual tests for nitrous fumes (NO₂) at various collieries over 24 hours

Colliery.	District.	Duration of Test (days).	Test.	Nitrous fumes as NO ₂ in parts per million.	Average.
A.3	a	13	(1)	4.0	} 4.0
		7	(2)	3.5	
		7	(3)	5.0	
		7	(4)	3.5	
A.3	b	—	(1)	3.1	} 3.2
		—	(2)	3.2	
A.6	a	14	(1)	2.2	} 1.9
		14	(2)	1.8	
		14	(3)	2.5	
		14	(4)	2.5	
		14	(5)	1.4	
		14	(6)	1.4	
A.9	a	29	(1)	2.8	2.8
A.9	b	33	(1)	4.9	4.9
A.2	a	16	(1)	1.4	} 2.0
		14	(2)	1.6	
		13	(3)	2.3	
		17	(4)	2.8	
A.2	b	12	(1)	0.3	} 1.2
		18	(2)	1.3	
		17	(3)	2.0	
A.7	a	19	(1)	0.9	} 0.8
		21	(2)	0.7	
		40	(3)	0.8	
A.7	b	21	(1)	1.5	} 1.4
		40	(2)	1.3	
A.4	a	16	(1)	2.6	} 2.6
		16	(2)	2.6	
A.4	b	16	(1)	4.4	} 4.5
		16	(2)	4.5	
A.8	a	14	(1)	2.6	} 2.0
		14	(2)	1.2	
		16	(3)	2.3	
A.8	b	17	(1)	2.3	} 1.8
		14	(2)	0.7	
		17	(3)	2.3	
S.4	a	8	(1)	1.2	1.2
S.4	b	7	(1)	1.2	1.2
A.3	Semi-hard heading	—	(1)	3.0	3.0
K.X	Hard heading	14	(1)	5.1	5.1

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by one of us in a heading in a North Staffordshire pit some years ago showed concentrations in the vicinity of a heap of debris, during the loading of the latter, eight hours after the shot had been fired, to be as high as 10 parts per million; this figure dropped to 2 parts per million after one hour, by which time all the debris had been cleared out. Similar results obtained in other pits confirm the tenacity with which the absorbed fumes remain in broken material, and findings suggesting the production of quite appreciable quantities of fumes on shifts during which no shot-firing has taken place may thus be explained. As an example of this, colliery B.3 (Table XCVI) showed an average of 3.1 parts per million, individual tests being between 2.4 and 3.7 parts per million (Table XCVIII), all firing having been done on the night shift and none during the following day shift during which the tests were made. Likewise, at colliery A.7 the average nitrous fumes production over about two hours showed

TABLE XCVIII

Values for individual tests for nitrous fumes (NO₂) at various collieries over period of shift

Colliery.	District.	Duration of Test (days)..	Test.	Nitrous fumes as NO ₂ in parts per million.	Average.
A.1	a	9	(1)	1.9	} 2.3
		6	(2)	2.1	
		4	(3)	3.5	
		7	(4)	2.5	
		4	(5)	2.8	
		8	(6)	1.7	
		7	(7)	2.0	
		6	(8)	3.2	
		11	(9)	2.0	
		13	(10)	1.3	
A.3	a	7	(1)	4.3	} 4.1
		6	(2)	4.3	
		7	(3)	3.4	
		6	(4)	4.5	
A.2	a	6	(1)	2.6	} 2.5
		10	(2)	2.6	
		9	(3)	2.3	
A.5	a	5	(1)	5.8	} 4.9
		4	(2)	7.6	
		5½	(3)	3.2	
		5½	(4)	2.8	
S.4	a	12	(1)	0.9	} 2.1
		7	(2)	1.7	
		13	(3)	1.5	
		8	(4)	2.9	
		4	(5)	3.9	
		23	(6)	1.5	
B.3	a	8	(1)	3.7	} 3.1
		5	(2)	3.7	
		12	(3)	2.4	
		6	(4)	2.5	
A.1	Hard heading	29	(1)	3.2	} 5.0
		26	(2)	4.6	
		57	(3)	7.2	
Sm.X ..	Hard heading	14	(1)	6.4	} 6.4

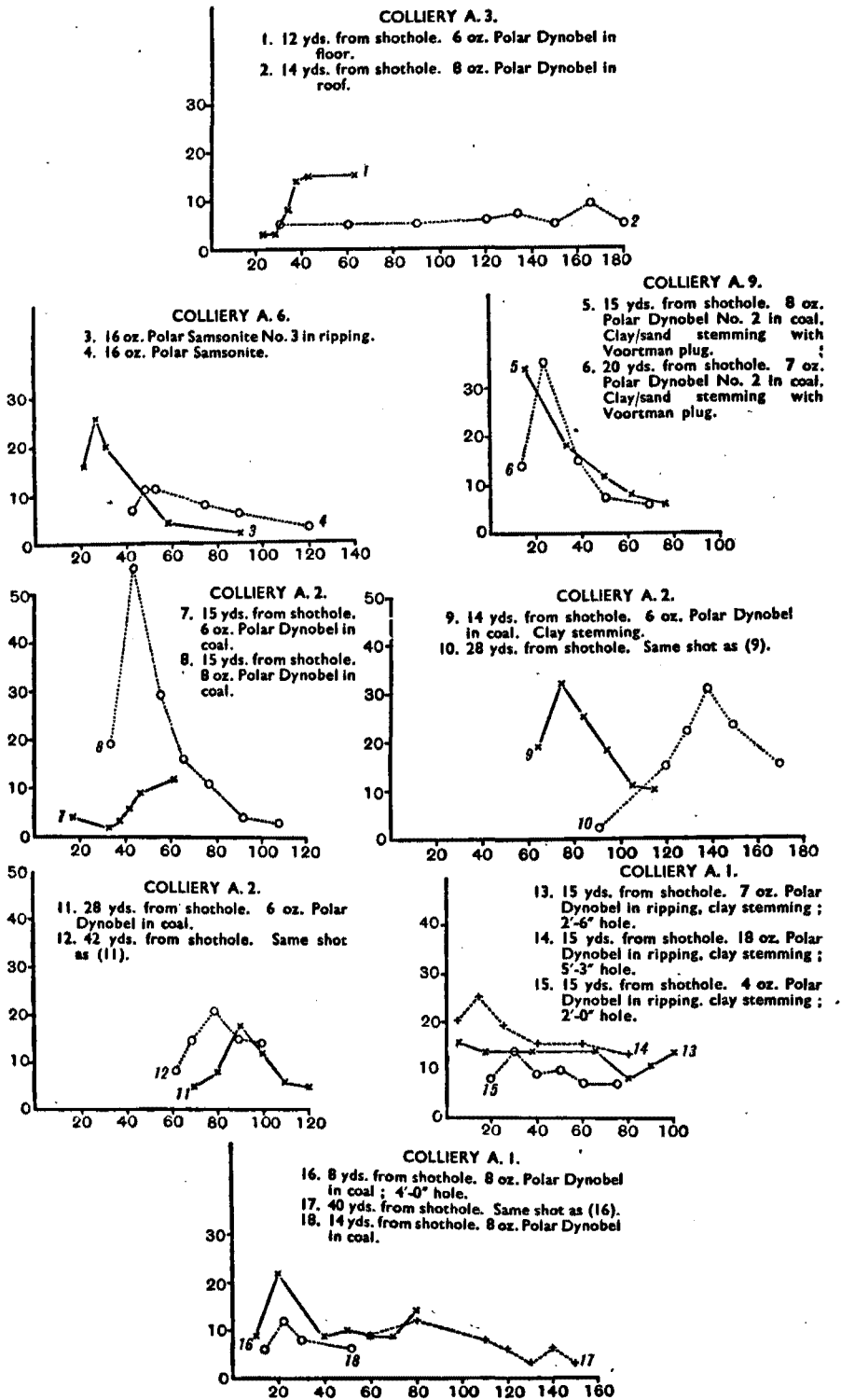


FIG. 16.—Concentration of nitrous fumes (expressed as NO_2) immediately after shot-firing at the coalface. The ordinates represent the concentration in parts per million; the abscissae, the time in seconds.

TABLE XCIX

Individual shots : maximum concentration of nitrous fumes, and time of appearance after firing

Colliery.	Seam.	Quantity of air per min.	Site of shot-hole.	Distance from shot-hole. Yards.	Charge of explosive. oz.	Maximum NO ₂ production.		Remarks.	
						NO ₂ p.p.m.	At secs. after firing.		
A.1	Lower Pumpquart ..	1,000	Face ripping	15	7	Polar Dynobel	16	5	2 ft. 6 in. hole, clay stemming.
			Face ripping	15	18	Polar Dynobel	25	15	5 ft. 3 in. hole, clay stemming.
			Face ripping	15	4	Polar Dynobel	14	30	2 ft. 0 in. hole, clay stemming.
			Face ripping	8	8	Polar Dynobel	22	20	4 ft. 0 in. hole, clay stemming.
			Face ripping	40	8	Polar Dynobel	12	80	Same shot.
			Face ripping	14			12	22	
A.2	Lower Pumpquart (a)	4,500	On face, coal	15	2	Polar Dynobel	9	65	Same shot.
				40			19	81	
			On face, coal	35	2	Polar Dynobel	12	35, 45	Same shot.
		60			16	50			
	(b)	4,500	Top hole, coal	15	6	Polar Dynobel	12	62	Same shot, clay stemming.
			Top hole, coal	15	8	Polar Dynobel	56	44	
			Top hole, coal	14	6	Polar Dynobel	32	75	
				28			31	139	
			Top hole, coal	28	6	Polar Dynobel	18	90		Same shot, clay stemming.
	42			21	79				

A.3	Stanlyd (a)	14,000	Coal ..	12	6	Polar Dynobel	5	16-24	
			Fireclay floor	12	6	Polar Dynobel	15	43-63	
			Roof	14	8	Polar Dynobel	9	165	
	(b)	2,000	Coal ..	10	10	Polar Dynobel	16	20	
	(c)		1,000	Ripping ..	10	5	Polar Dynobel	40		55
			Semi-hard heading	22	10	Polar Dynobel	39	180	Ventilated with compressed air.
			Off roof ..	—	6	5 mins. later			
A.4	Stanlyd (a)	8,000	Coal ..	9	7	Polar Dynobel	6	43	Ventilation off.
				10	8	Polar Dynobel	17	51	
				—	—	—	40	180	
A.5	Red Vein (a)	5,600	—	—	—	35	300-400	Sluggish ventilation. Damp ?	
A.6	Red Vein	10,000	Ripping ..	40	16	Polar Samsonite	26	27	Voortmann plug clay/sand stemming.
			Ripping ..	34	16	Polar Samsonite	4	48-50	
A.9	Lower Pumpquart (a)	7,000	Coal ..	15	8	Polar Dynobel No. 2.	16	34	
			Coal ..	20	7	Polar Dynobel No. 2.	35	14	
			Coal ..	—	—	Polar Dynobel No. 2.	30	30	
			Coal ..	—	—	Polar Dynobel No. 2.	20	45	
			Coal ..	52	8	Polar Dynobel No. 2.	34	32	
A.X	—	—	Coal ..	60	—	Polar Dynobel No. 2.	18	28	Dry.
S.4	Two feet, 9 in. ..	—	Ripping ..	23	20	Polar Viking ..	51	45	After passing through spray.
				12	8	Polar Viking ..	38	30	5-in. hole damp ?
				15	20	Polar Viking ..	15	205	3 ft. 1 in. sand/stone.
								2 ft. 8 in. hole.	
								4 ft. 0 in. hole.	

TABLE C

Concentration of nitrous fumes after shot-firing in hard headings (determinations of nitrogen dioxide made by J. Ivon Graham and F. Lawrence, 1935-36)

<i>Colliery and District in which mine is situated.</i>	<i>Mist projector used or not.</i>	<i>Nature of rocks.</i>	<i>No. of holes.</i>	<i>Explosive.</i>	<i>Charge.</i>	<i>Conc. of NO₂ Parts per million.</i>	<i>Remarks.</i>
Colliery X, Somerset, January, 1935.	No spray	Greys	4	Polar Viking ..	36	10	After 1½ min.
						25	3 min.
	No spray	Greys	3	Polar Viking ..	36	35	After 1 min.
						10	3 min.
						30	8 min.
	With solution of Per- minal W.	Greys	3	Polar Viking ..	42	Under 10	22½ min. (at face).
						150	1 min. after.
						10	3 min. after.
						5	5 min. after.
Colliery X, Somerset, August, 1935.	Colliery spray on for 2 min. after shot fired.	Greys	2	Polar Viking ..	24	18	
		Greys	4	Polar Viking ..	54	35	
September, 1935.	With water	Greys	5	Polar Viking ..	60	50	
	No	Greys	3	Polar Viking ..	44	40	
December, 1935.*	—	—	15	Polar Viking ..	160	40	2 hrs. after blasting (15 shots 10 lb. explosive used).
	With water	—	1	Polar Viking ..	15	55	
	With water	—	1	Polar Viking ..	15	40	
	With water + wetting agent (Siotol).	—	1	Polar Viking ..	16	76	

Cumberland (Ironstone Mine), March, 1935.	Wetherall spray ..	Ironstone	4	Gelemex ..	96	6	} (1) 8 min. after. (2) 2 min. after. 5 min. after. (3) 1½ min. after. (4) 4 min. after. (5)
	No spray	Ironstone	4	Gelemex ..	96	30	
	No spray					10	
	No spray	Ironstone	2	Gelemex ..	48	50	
	No spray	Ironstone	2	Gelemex ..	48	45	
	No spray	Ironstone	2	Weberlox (liquid oxygen).	24	13	3 cartridges.
Colliery D, N. Staffs, August, 1935.	No spray	Shale	5	Kentite ..	44	35	} Average over first 5 min. after firing shot.
	Water	Shale	4	Kentite ..	28	50	
	Castor oil and water	Shale	3	Kentite ..	34	50	
Colliery A, Cannock Chase, October, 1935. February, 1936 ..	No spray	Shale	1	Polar Samsonite	8	17	This shot did its work well.
	Colliery Spray ..		1		8	56	
	Brown-Hay of Cumberland		1		8	19	
			1		8	38	
	Water (Colliery spray)		1	Polar Samsonite	70		
	Water (Colliery spray)		2	Polar Samsonite	55		
Water + wetting agent	1	Polar Samsonite	60				
Water (Colliery spray)	1	Polar Samsonite	20				
Colliery B, Warwickshire, February, 1936.	No spray	Hard Sandstone	1	Polar Ajax ..	16	1	Borehole and rock being fired under water. Before shot fired borehole above water. ½-5 min. after shot fired. 5½-9 min. after shot fired. Half an hour after shot—near face of heading.
	No spray		2	Polar Ajax ..	12	1	
						50	
						20	
						10	

* December tests—fan not in use except immediately after shotfiring.

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a concentration of 2 parts per million, although no shot firing had taken place during that period. In some cases the average quantity over the shift has been found to be only about the same as that measured over the full 24 hours. For example, in colliery A.3, district "a", 4.1 parts per million were found in the shift test, as against 4 parts per million over 24 hours. The former tests, however, were made nearly two years earlier, so that conditions may not have been strictly comparable, and further it will be noted that the quantity of explosive used in coal was 0.11 oz. per ton, against 0.24 oz. per ton during the earlier 24-hour tests. In the case of colliery A.2, district "a", there was a consumption of explosive of 3.30 oz. per ton of coal, and 3.67 oz. total, during the shift tests, as compared with 3.55 oz. per ton of coal, and 3.82 in all, over the 24 hours, whereas the average concentration of nitrous fumes over the working shift was 2.5 parts per million, against 2.0 parts per million for the 24 hours. In the steam coal pit, S.4, no shots were fired in the coal, all shot-firing being done on ripping work during the afternoon shift. The tests at this colliery were therefore carried out during the afternoon shift. Reference to Tables XCV and XCVI shows that the quantity in the afternoon shot-firing shift was roughly twice that for the 24 hours, but when the latter tests were carried out the amount of explosive had increased from 0.18 oz. per ton to 0.38 oz. per ton. In colliery B.3, firing is done on the night shift, and, as already mentioned, a relatively high average was obtained over the following day shift.

Numerous tests have also been carried out to determine the concentrations of fumes momentarily in the immediate vicinity of the shot. Reference has already been made (p. 193) to the procedure adopted for the taking of samples in evacuated tubes at intervals of a few seconds. A position was chosen in the return side of the shot, as near as possible to the latter, and in several cases two positions were taken for the same shot, in order to ascertain the effect of distance upon the dissipation of fumes. Usually six or eight samples were taken and the concentration of nitrogen dioxide plotted against time. A large number of shots were investigated at several of the collieries, and data respecting thirty-three of these are included in Table XCIX, in which is recorded the maximum value obtained for each shot. Fig. 16 shows the results of several of these tests in graphical form, in which the concentration is plotted against the time. It will be seen that the shape of the curve varies with different shots. In some cases the falling off of nitrogen dioxide concentration with time is relatively small; but in most of the graphs a well marked maximum is evident, the concentration then dropping rapidly, usually within a minute, until it is less than 5 parts per million. Where the ventilation is good, and where the cross-sectional area at the face is not great, any high concentration immediately following the firing of the shot will be quickly diluted, and, in consequence, the curve relating nitrogen dioxide concentration with time will be of the shape shown in Fig. 16, curves 3-12. (The high concentration of nitrogen dioxide indicated in curve 8 was probably due to overcharging of the shot-hole.) Samples from the same shot taken at different distances (Fig. 16, curve 11 and 12) indicate the absorption of fumes resulting from dampness at the coalface. Where the ventilating current is sluggish, the fumes will clearly take longer to be dissipated, and a curve of the type shown in Fig. 16, curves 13-17, will result. The fumes may be present for only a very short time at any one spot if the velocity of the air current is high, and, obviously, the average concentration will depend upon the total quantity of fresh air passing the shot-hole. The cross-sectional area of the air-way in the vicinity of the shot-hole will also affect the shape of the graph, since with a greater area there will be a larger volume of air for immediate dilution of the fumes. It is probable, also, that the amount of fine material produced by the shot, or that already lying in the vicinity of the shot-hole, will, by absorption and subsequent slow desorption of fumes, affect the shape of the curve.

The results given in Table C and in Figs. 16 and 17 show quite clearly that the quantity of fumes does not depend upon the amount of charge. Thus, comparison of the curves for two shots of 6 oz. of polar dynobel, the sampling point being 28 yards away in each case (Fig. 16, curves 10 and 11), shows that considerably more fumes were produced in the first case than in the second. Again, for colliery S.4, Fig. 17, curves 19 and 20 show that the total quantity of nitrogen dioxide was much greater for one shot than the other, although each hole was charged with the same quantity of explosive, viz. 20 oz. of polar viking, a 3 : 1 sand/stone-dust stemming being used in each case. These results simply confirm the opinion held by experts in shot-firing that the correct placing of a hole, and the charging of this with the right amount of explosive, are of more importance than the actual size of the charge.

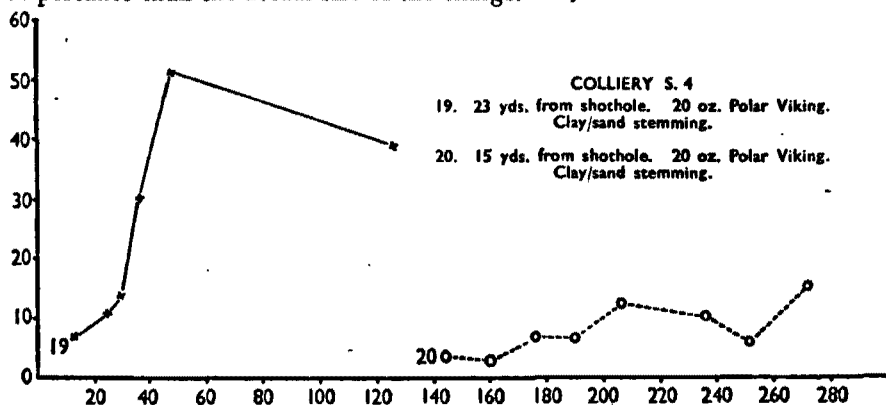


FIG. 17.—Concentration of nitrous fumes (expressed as NO_2) immediately after shot-firing at the coalface. The ordinate represents the concentration in parts per million; the abscissa, the time in seconds.

It may be of interest at this stage to compare the production of fumes at the coalface with similar findings in respect of hard headings. In the latter, the rate of dispersal of the fumes likewise depends upon the amount of ventilation, and there is no doubt that in the past the ventilation of many headings has not received sufficient attention, from the point of view of removal of dust as well as of fumes after shot-firing. In the present investigation, samples have been taken in three headings. One series was obtained at colliery A.3, in what may be described as a semi-hard heading, the lower portion of the heading being in coal and the upper in rock, the proportion of rock removed to coal being approximately 4 : 1 and the ventilation being by means of air released from a compressed air main to the extent of 1,000 cu. ft. per minute. With this ventilation, the maximum concentration 22 yards back from the face of the heading was 39 parts per million 3 minutes after a second shot of 6 oz. of polar dynobel had been fired, the first shot, of 10 oz., having been fired 5 minutes before the second.

Fig. 18, curves 21 and 22, illustrate the production of fumes with relatively heavy shots in a hard heading driven in "greys" in a Somerset colliery, the ventilation being by means of a 1-in. pipe from the compressed air main, releasing approximately 1,000 cu. ft. of free air per minute; Fig. 18, curves 23 and 24, are for a hard heading in a Kent colliery, which had a cross-sectional area about 50 per cent. greater than that of the Somerset heading and was ventilated by two and a half times as much air. The Somerset "greys" is notorious for its toll of workers through silicosis, whilst the incidence of the disease at the Kent colliery has not been negligible. Curve 23a shows the average concentration of fumes over the period of the test, as determined with the aspirator. Curve 25 relates to shots fired in the Kent colliery heading when

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a "mist projector" was in operation for a couple of minutes before and for 2½ minutes after the shot was fired. The curve shows the reduction of fumes while the mist was in operation. This method of reducing the amount of dust and fumes after shot-firing will be discussed later. The amount of explosive used per diem, and other particulars relating to these two headings, are included in Tables XCV and XCVI, which give the average concentrations of fumes produced during 24 hours in the case of hard heading in the Kent colliery, and the average

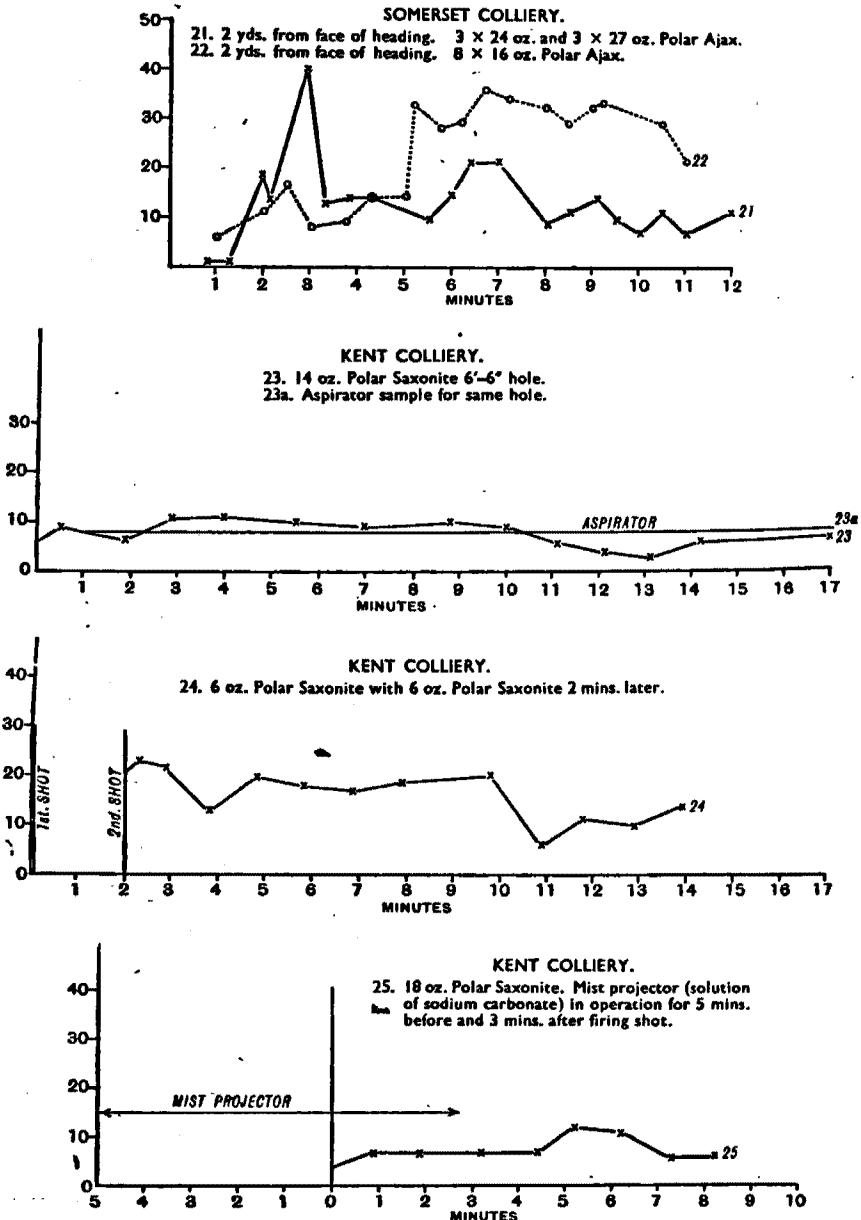


FIG. 18.—Concentration of nitrous fumes (expressed as NO_2) immediately after shot-firing in hard headings. The ordinates represent the concentration in parts per million; the abscissae, the time in minutes.

for the shift in the case of the Somerset colliery. It will be noted that these are the highest averages obtained in the course of the investigations. The results of some earlier determinations, made by one of us between 1934 and 1937, in various hard headings throughout the country are included in Table C, from which it will be seen that figures were obtained of the same order as those found on the coalface in anthracite collieries for a short space of time after firing. Owing to the smaller amount of ventilation usually existing in these hard headings, and, in general, the much greater quantity of explosive used, the concentrations shown exist for a longer period, and in consequence workers are probably exposed for a correspondingly longer time than on the coalface of an anthracite colliery. An exception, of course, will be where arrangements have been made to employ suctional ventilation for headings, by which the gases and dust are drawn away through ducting without passing over the workers. Unfortunately, such an arrangement is not very common and has the great drawback that it is difficult to clear firedamp from the upper sections at the face of the heading unless the force of a positive ventilating current (or forced ventilation) is taken to the face. This drawback can be overcome by the use of an auxiliary fan for blowing the air to the face of the heading.

DISCUSSION OF RESULTS IN RELATION TO INCIDENCE OF PULMONARY DISEASE

For the convenience of the reader, the results obtained in the course of the investigation are given in a summarized form in Table C1; this also shows the observed incidence of pulmonary X-ray abnormalities ("consolidations") amongst coalface workers as a percentage of the expected incidence and, in addition, the results for the average concentrations of dust as determined by

TABLE C1

Summary of results—showing average concentrations of nitrous fumes in relation to incidence of pulmonary X-ray abnormalities; also average dust concentrations at working face during working shift.

Colliery	Observed incidence of X-ray abnormalities ("consolidations") amongst coalface workers as percentage of expected value.	Average concentration of nitrous fumes (NO ₂) in parts per million.		Dust concentration during working shift, m.g. per cu. metre.		Working conditions in regard to dryness.
		Over 24 hours.	Over working shift.	All.	Dust other than coal.	
A.1	233	—	2.3	{ 99.5 136.7 }	{ 6.1 17.2 }	Dry and deep.
A.6	176	1.9	—	—	—	" " "
A.3	172	3.6	4.1	65.6	3.8	" " "
A.8	146	1.9	—	{ 166.1 152 }	{ 7.5 20.5 }	" " "
A.7	95	1.1	—	—	—	" " "
A.4	55	3.5	—	—	—	Dry and medium depth.
A.2	12	1.6	2.5	82.2	2.4	Damp and shallow.
S.4	12	1.2	—	—	—	Dry and deep.
B.3	4	—	3.1	23.5	4.8	" " "
A.5	0	—	4.9	60	7.0	Damp and medium depth.
B.2	0	—	—	94	25.8	Dry and deep.

* Figures in italics are those obtained by Drs. Bedford and Warner. The remainder were obtained by A. S. Crawford and J. Ivon Graham.

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Drs. Bedford and Warner and/or one of the authors of the present report assisted by Mr. A. S. Crawford.

The concentration of nitrogen dioxide or nitrous fumes in the atmosphere at the coalface in anthracite mines amounts, on the average, to only three or four parts per million. On comparing the incidence of pulmonary X-ray abnormalities reported in the medical survey with the average figures for nitrous fumes at the various mines—either when tested over the 24 hours or on shift only—it will be seen that there is no definite relation between them. The production of nitrous fumes, or the concentration of these, would not therefore seem to be the most important factor in the causation of chronic pulmonary disease. The results, however, do not by any means exclude the possibility of continued exposure to small concentrations being an auxiliary factor of importance. It is not known how far the effects of exposure to a relatively high concentration of fumes for a short time may be compared with those of exposure to a lower concentration over a longer period. For example, men working at the intake end of a face, where there may well be less ventilation than at the return end, owing to leakage down gate roads, may be exposed temporarily to higher "peak" concentrations after shot-firing than will be the case with workers at the return end of the face. There is, unfortunately, little direct evidence as to the effect produced by exposure to such low concentrations for prolonged periods, and what evidence is available is not conclusive. As already mentioned on p. 190, the experimental work of Robson, Irwin & King at Toronto, suggested that serious effects could result from exposure to 100 parts per million even for relatively short periods, and particularly if the exposure to gas was accompanied by exposure to free silica. The Toronto experiments showed that widespread damage occurred to the lungs of rabbits exposed for 2 hours per diem for two weeks—i.e., a total of 28 hours—to 0.01 per cent., or 100 parts per million, of nitrogen dioxide, although no evidence of "acute" poisoning was obtained. The question arises whether exposure to one-twentieth of this amount, or 5 parts per million, for a period of about 600 hours would likewise cause damage to the pulmonary system. Vigdortschik and collaborators (1937) record that 127 men working for 3 to 5 years in concentrations of nitrogen dioxide of the order of only 2.5 parts per million showed evidence of chronic poisoning, which is attributed to the nitrous fumes. With the average concentration of nitrous fumes during the working shift at colliery A.5, an exposure for 560 hours might, on the basis of the Toronto experiments, be considered likely to produce harmful effects. In other words, something like 100 shifts might be harmful to rabbits and, so far as we can judge from Lehmann and Hasagawa's results, these animals are no more sensitive than man to concentrations of the order of 100 to 200 parts per million. There is, however, the probability that the lungs may recover during periods between exposure (*vide* "Report of the work of the Mining Research Laboratory for the 2 years ended March 31st, 1941", reference to work of F. Haynes). There would, nevertheless, appear to be some real evidence that prolonged exposure to concentrations greater than 50 parts per million may be followed by detrimental effects upon the pulmonary system, due to nitrogen dioxide either by itself or in conjunction with dust.

As already pointed out, the results obtained in our investigations do not indicate any connection between the incidence of pulmonary disease, as shown by the X-ray abnormalities, and the average production of nitrous fumes. Unfortunately, however, it is not possible to be sure that the tests carried out by us cover conditions identical with those under which men worked some years ago. In view of the present uncertainty of our knowledge as to the concentrations which may cause damage to the pulmonary system, it is clearly desirable to minimise risk by taking every possible precaution to reduce the concentration of nitrous fumes to a minimum.

SUGGESTED MEANS FOR REDUCING NITROUS FUMES IN ANTHRACITE MINES

Methods which could be used to minimize the possible hazard from nitrous fumes include the following :—

- (1) Reduction of shot-firing to a minimum.
- (2) Firing of shots on back shift.
- (3) Prevention of escape of fumes to the atmosphere.
- (4) Removal of fumes from the atmosphere before they can pass over workers in the vicinity.

(1) *Reduction of shot-firing to a minimum.*—Owing to the toughness of anthracite, some method, other than by hand alone, for breaking down the coal is nearly always necessary, but the findings in our investigation indicate that over-charging of shot-holes with explosive is common. By the use of a stemming plug for controlling the length of air gap between the charge and the stemming, it has been claimed that nitrous fumes may be eliminated or considerably reduced. After careful tests, we conclude that such special devices will be of help only when they ensure a reduction in the amount of explosive to a quantity which is just sufficient to do the work required—in other words, if they eliminate overcharging (*cf.* also Holtz and Murphy, 1942). The hydraulic coal burster has been used successfully in many bituminous mines, as an alternative to shot-firing; but so far this does not seem to have been applied to any large extent in the anthracite area, no doubt owing to the relative toughness of anthracite. Modification of the burster to render it more suitable for anthracite would not appear to be impossible.

Pneumatic picks are being used with success in some anthracite collieries, but they have the disadvantage of increasing the amount of dust at the coalface. The addition to the pneumatic pick of a simple form of water spray is not impracticable, and such a contrivance should undoubtedly help to suppress dust in the cracks into which the pick is usually driven, as well as the dust caused by the pick itself; this method is being investigated through the Mining Research Laboratory.

(2) *Firing of shots on back shift.*—Some anthracite and bituminous collieries now adopt the principle of doing all, or almost all, shot-firing on the back shift. The investigations described in this report show that this procedure will not eliminate the fumes completely, since a large proportion of the nitrogen-dioxide is absorbed by the dust in the vicinity and subsequently given off slowly to the air. Nevertheless, the high peak concentrations encountered at the coalface after the firing of a shot will be eliminated and these may possibly be more harmful than prolonged exposure to a low concentration; limitation of shot-firing to the back shift will certainly help to reduce exposure to high concentrations of fumes, as well as to the dust raised as a cloud during shot-firing.

(3) *Prevention of escape of fumes to the atmosphere.*—The use of the sheathed cartridge, in which an envelope of sodium bicarbonate surrounds the explosive, is common in many bituminous collieries, but this has not been used to any great extent in the anthracite areas. One objection to the sheathed cartridge is that its use involves the drilling of a much larger borehole than customary—which is difficult, no doubt, in anthracite, unless power is available for the use of a rotary drill. It has been suggested that with sheathed cartridges practically no nitrous fumes are formed, but this is contrary to our experience and that of other observers. A sheathing which includes, with the sodium bicarbonate, a small quantity of ammonium carbonate will, it is believed, be more effective in reducing fumes than one of sodium bicarbonate alone.

Clearly, any simple method by which the coal *in situ* can be wetted at the time of shot-firing, or just before it, will help to reduce the amount of both dust and fumes. For example, the application of water stemming (water

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in a carton) has been tentatively tried by the authors, and the results indicate that this method may be worthy of further study—particularly if a dilute solution of ammonium carbonate be used in place of pure water.

(4) *Removal of fumes from the air before they can pass over workers in the vicinity.*—A proposal which has been tested to a greater extent under practical conditions is the use of a mist of a solution of sodium carbonate or a mixture of the latter with a small quantity of ammonium carbonate. Obviously, a mist of water or of alkaline solution can have little effect upon the nitrous fumes if these consist mainly of nitric oxide, unless by its action it helps to promote the rapid oxidation of nitric oxide to nitrogen dioxide.

The removal of nitrous fumes by means of the Hay mist projector has been demonstrated in hard headings in several collieries. Fig. 18, curve 25, illustrates the beneficial action of the Hay mist projector in reducing nitrous fumes, and Table C gives a case in which the production of an unusually large amount of nitrogen dioxide was countered by a mist of water and a wetting-agent. The results recorded in Table C do not indicate any general improvement from the use of a mist or spray, but this is probably due in part to the fact, already noted, that equal weights of explosive do not necessarily give the same concentrations of nitrous fumes, and in part to a relatively high proportion of nitric oxide in the fumes.

Fig. 19, curves 26 and 27, illustrate the beneficial effect which was derived even by passing the air laden with dust and fumes through a spray which was far from efficient and where the air velocity was 300 ft./minute. Tests in the experimental gallery of the Mining Research Laboratory about five years ago showed that, with the passage of air containing 100 parts per million of nitrous fumes (calculated as nitrogen dioxide) through a mist of sodium carbonate solution from a Hay mist projector, the fumes were absorbed so completely as to give no reaction with potassium iodide and starch paper, whereas without the mist a strong coloration was produced.

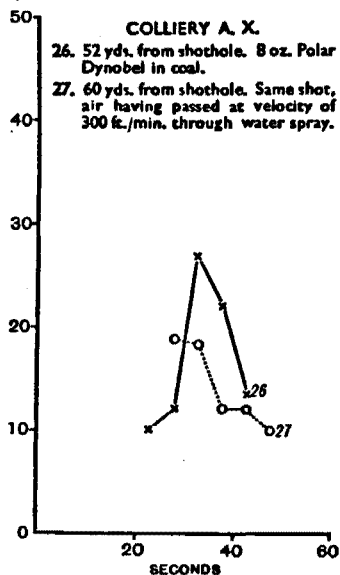


FIG. 19.—Illustrating effect of passing fumes from shot-firing through water spray. The ordinate represents the concentration of nitrous fumes (expressed as NO_2) in parts per million; the abscissa, the time in seconds.

The use of the mist projector for the suppression of fumes has also been tried, with promising results, at the face of an anthracite mine, a very dilute solution of ammonium carbonate being employed in place of water. Such procedure will obviously be beneficial from the point of view of suppressing dust, as well as of removing nitrogen dioxide. The use of a mist on the coalface while colliers are at work is impracticable, but for the short space of time required to deal with the fumes and dust from a coalface shot the miner will not feel any discomfort, since obviously he must be away from the face at the time of the shot. The Hay mist projector requires a supply of compressed air, which is not always available at the coalface, and, as an alternative for such cases, a tank fitted with sprays and pump for producing the necessary mist has been designed, and is being tested in the Mining Research Laboratory.

It has been pointed out in this report that our tests have not distinguished between nitric oxide and nitrogen dioxide. The physiological and pathological effects of these two gases may be very different, and, although the work of Pflessner (1935) has indicated that nitric oxide may be rather more toxic than nitrogen dioxide when inhaled in concentrations greater than 0.04 per cent., it is possible that the difference may not hold at lower concentrations. We believe that further investigation should be made of the effects of each of these two gases in concentrations of the order of a few parts per million, and also of the ratio in which nitric oxide and nitrogen dioxide occur during and immediately after shot-firing.

ACKNOWLEDGEMENTS

In conclusion, we should like to express our gratitude to the managements and staffs of those collieries of Amalgamated Anthracite, Ltd., and other pits where the investigations have been made, for their unflinching courtesy and readiness to assist us. Thanks are due also to Major R. Yates and Mr. A. Taylor, of the Mines Department Inspectorate, for their interest and help during the investigations; to Messrs. F. Lawrence and H. A. Stanley for aid on the laboratory side and to Miss F. K. Franks for assistance in the preparation of the manuscript of this report. Finally, we wish to record our indebtedness to the Safety in Mines Research Board for its help on the financial side, which made the investigation possible.

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APPENDIX I

ABSTRACT OF REPORT ON THE SOLUBILITY OF MINERALS AND
MINERAL GELS IN AQUEOUS DIETHYLAMINE*By Geochemical Laboratories, London*

The work to be described was carried out on behalf of A. Brammall and J. G. C. Leech, with the object of obtaining further evidence regarding the nature of the groundmass constituents of South Wales shales and, in particular, ascertaining whether an amorphous silico-alumino-gel was present.

For this purpose base-exchange and solubility determinations were carried out on both original shales and 2μ fractions separated by means of air-elutriation.

Extraction with sodium hydroxide or sodium carbonate could be relied on to remove silica, alumina and silico-alumino-gels; doubtless such factors as temperature, time of extraction, concentration of alkali, etc., could be so adjusted as to reduce to a minimum any attack on the crystalline minerals.* Nevertheless, it seemed possible that more satisfactory results would be achieved by the use of an organic base, and attention was directed to the work of B. Sjollem (J. Landwirtschaft, 1902, 50, 371), who describes the separation of quartz from amorphous silicates with the aid of aqueous diethylamine. Other organic bases, e.g. pyridine, aniline, methylamine and trimethylamine, appeared to offer no advantages over aqueous diethylamine, and it was decided to employ the latter for the extraction of the shales received.

Solubility of gels in aqueous diethylamine

Sjollem describes the separation of quartz from "amorphous silicates" by refluxing with aqueous diethylamine; but no clue is given to the composition or origin of the silicates used in his experiments. Accordingly, at the outset of our investigations a number of gels were prepared and examined as regards solubility in the above medium.

Silica gel, prepared by acidifying a solution of sodium silicate with dilute hydrochloric acid, was almost insoluble in pure diethylamine but dissolved on refluxing with an aqueous solution containing one part by volume of diethylamine to two parts of water.

The pH of the latter solution (thymol-violet indicator) was greater than 13.0, and the strength of this base approaches that of caustic soda. Silica gel which had been fumed with sulphuric acid, and the dried form supplied for laboratory use as a desiccant, were also soluble (Table CII below). The filtered solutions were perfectly clear and could be refiltered without change in concentration through asbestos pads of the type used in bacteriological work for the removal of micro-organisms. The solutions were, however, colloidal and exhibited a well marked Tyndall effect. Addition of excess ammonium chloride or ammonium nitrate caused flocculation.

Procedure in these experiments was as follows:

Approximately 0.4 g. of silica gel was placed in a glass flask fitted with a ground-glass joint carrying a condenser and refluxed on a water bath for 3 hours with 30 ml. of 2 : 1 aqueous diethylamine.

The solution was filtered through a "sterimat", Grade S.B., and evaporated to dryness in a platinum basin. A few drops of sulphuric acid were added and the dish was slowly heated until sulphuric acid and organic matter had been removed.

After igniting to redness for a short time, the dish was cooled and weighed, and the residue treated with hydrofluoric acid. Blank determinations, carried out in exactly similar manner, yielded not more than 1.5 mg. extract, of which approximately 0.5 mg. was silica.

Alumina gel was less soluble than silica gel, 30 ml. of the solvent extracting only 0.015 g. of the freshly precipitated hydroxide prepared by the addition of ammonia to a solution of aluminium chloride.

Ferrous and ferric hydroxides were insoluble under the conditions of test.

Aluminium silicate gels. According to S. Mattson, the formation of the clay complex in soils is analogous to the mutual precipitation of a positive alumina sol by a negative silicic-acid sol under isoelectric conditions—when no electric charges are present on the precipitated alumino-silico-gel. The composition of the isoelectric precipitate varies according to the pH of the solution and the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio, being approximately 2.4 at pH 4.5 and zero at pH 8.0.

Attempts to reproduce these conditions in their entirety were unsuccessful, and $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios were limited in range 1.15–1.65.

The procedure was to mix a solution of aluminium chloride (5 millimols per litre) with a solution of sodium silicate (10 millimols per litre) and to adjust the pH of the solutions by precipitating in the presence of hydrochloric acid or sodium hydroxide. After vigorous stirring, the precipitate was then separated by centrifuging.

* The structure of silica and alumina gels has a material bearing on their solubility in alkaline reagents (Ganguli, A., *Acta Physicochem. U.S.S.R.*, 1938, 9, 19; Lourky, A. R., *Z. anorg. Chem.*, 1939, 240, 198).

Aluminium silicates prepared in this way were readily soluble when refluxed with aqueous diethylamine, and they also dissolved in the cold solvent. When dried at 105° C. the gels appeared to become somewhat less soluble, although even under these conditions approximately 0.2 g. of gel could be dissolved in 30 ml. 2 : 1 aqueous diethylamine.

Mixtures of silica- and alumina-gels. Freshly prepared silica gel is very soluble in 2 : 1 aq. diethylamine, but it is insoluble or nearly so in a saturated solution of alumina gel in the same reagent (i.e. 0.015-0.020 g. alumina gel in 30 ml.).

Mechanical mixtures of silica and alumina gels in widely different proportions yielded only minute amounts of silica when extracted with aqueous diethylamine. As the ratio of silica to alumina gel is increased, the amount of silica extracted rises slightly, but even when the molecular proportions of the two gels are 9 : 1 it does not exceed 10 mg. *There is, therefore, very definite evidence that alumina exerts a protective action on silica gel.*

When alumina gel is refluxed for about $\frac{1}{2}$ hour with aqueous diethylamine, micro-crystalline needles are deposited. Under the microscope, these crystals are seen to be of an embryonic type, and to exhibit birefringence (with straight extinction). The crystals apparently consist of aluminium oxide, probably in a hydrated form. It is not yet certain whether the formation of these crystals is connected with the protective action of the gel, although in this connection it is of interest to note that L. H. Germer and K. H. Stocks (*Chem. Tr. J.*, 1939, 104, 382), in the course of their work on the protective action of aluminium powder, have shown by X-ray diffraction measurements that aluminium combines with water to form a crystalline hydrate ($Al_2O_3 \cdot 3H_2O$), which is then deposited on the surface of quartz particles.

The employment of aqueous diethylamine for dust-solubility determinations is open to the objection that the figures so obtained bear little relationship to solubility in body fluids. But, in the present instance, its use is justified by the fact that *the primary object of the experiments was to endeavour to differentiate between the amorphous and the crystalline constituents forming the groundmass of the South Wales shales.* For the latter purpose, an alkaline reagent in which silica, alumina and aluminosilico-gels are all soluble is preferable to water or to physiological salt solution.

Experimental procedure

In order to obtain comparable results, it was necessary to standardize the conditions under which solubility determinations were carried out, and, unless otherwise stated, figures quoted in this report refer to the extract obtained when a 0.5 g. sample was refluxed for 3 hours with 30 ml. 2 : 1 aq. diethylamine, the operation being performed on a water bath in glass flasks (150 ml. capacity) fitted with ground-in reflux condensers. The solution was then filtered through a Ford "sterimat" contained in a Gooch crucible, transferred to a platinum dish and evaporated to dryness. A few drops of sulphuric acid were added and the dish placed on a hot plate until fuming had ceased. The residue was gently ignited to remove carbonaceous matter and weighed. Blank determinations made under precisely similar conditions yielded approximately 1 mg. extract.

Filtration was not regarded as satisfactory until a perfectly clear solution was obtained, but normally only one filtration was necessary. In the event of turbidity the solution was refiltered through the original pad. The pores in these filter pads are small enough to remove all coarse colloidal particles but permit silicic acid solutions to be filtered without change in concentration. The average pore space of the grade employed needs to be taken into consideration in the interpretation of results.

TABLE CII
Gels

Description of gel.	Mol. ratio SiO_2/Al_2O_3 in gel.	Total extract.	Mol. ratio SiO_2/Al_2O_3 in extract.	Remarks.
(0.4 g. approx.)		g.		
Fresh silica	—	0.42	—	Solution complete.
Silica gel (dessicant) ..	—	0.105	—	Some excess gel.
Fresh alumina	—	0.015	—	Some excess gel.
Aluminium silicate ..	1.15	0.0517	1.15	Solution complete in the cold.
Aluminium silicate ..	1.41	0.1093	1.41	Solution complete.
Aluminium silicate ..	1.65	0.2275	1.65	Solution complete.
Aluminium silicate (dried) ..	—	0.1865	1.4	Some excess gel.
SiO_2, Al_2O_3 mixed ..	0.65	0.0219	0.09	Some excess gel.
SiO_2, Al_2O_3 mixed ..	1.03	0.0117	0.21	Some excess gel.
SiO_2, Al_2O_3 mixed ..	1.3	0.0469	0.25	Some excess gel.
SiO_2, Al_2O_3 mixed ..	9.2	0.0206	1.5	Some excess gel.

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TABLE CIII

Minerals

<i>Mineral.</i>	<i>Weight of sample.</i>	<i>Weight of extract.</i>	<i>Mol. ratio SiO₂/Al₂O₃</i>
Quartz	g. 0.3	g. 0.0007	—
China clay, "Devolite"	0.5	0.0019	—
Fuller's earth (Nutfield)	0.5	Nil	—
London clay	0.5	Nil	—
Muscovite (Malvern) :			
1st extract	0.5	0.0142	1.0
2nd extract	—	0.0064	1.1
3rd extract	—	0.0025	—
<2 μ fraction (air elutriated)	0.5	0.0151	0.9
Slate (Delabole) (freshly ground)	0.5	0.0036	—
Slate dust (air blown)	0.5	0.0020	—
Bentonite (Wyoming)	0.5	0.0179*	—
Talc (Bergen), micronised	0.5	Nil	—

Blank deducted from all figures.

* Includes 0.0164 g. of alkalis.

TABLE CIV

Rocks of collieries A.2 and A.3

<i>Sample.</i>	<i>Weight taken.</i>	<i>Weight of extract.</i>		<i>Composition of extract.</i>		<i>Mol. ratio.</i>
		<i>g.</i>	<i>Per cent.</i>	<i>SiO₂.</i>	<i>Al₂O₃.</i>	
Colliery A.3 (C.) clod	0.5	1st extract	0.0214	0.0100	0.0111	1.6
		2nd extract	0.0061	0.0031	0.0026	—
		3rd extract	0.0027	0.0012	0.0015	—
		4th extract	0.0009	Nil	0.0010	—
	1.5	6.22				
		1st extract	0.0646*	0.0282	0.0325	1.5
		2nd extract	0.0187	0.0082	0.0092	1.5
	Colliery A.2 clod ..	0.5	3rd extract	0.0111	0.0049	0.0064	1.3
6.30						
Colliery A.2 clod ..	0.5	1st extract	0.0097	0.0043	0.0039	1.9
		2nd extract	0.0037	0.0013	0.0009	—
Sericite-rich crust-and-film :		2.68				
	Colliery A.2 ..	0.5	1st extract	0.0042†	0.0004	0.0002
Colliery S.4 shale ..	0.5	1st extract	0.0344	0.0170	0.0173	1.67

* Contains 0.0015 g. alkalis (as oxides).

† Contains 0.0020 g. alkalis.

TABLE CV

Fractions air-elutriated from clods of collieries A.2 and A.3

Sample.	Weight taken.	Weight of extract.	Weight of SiO ₂ in extract.	Particle Size.
Colliery A.3 clod.. .. .	g. 0.5	g. 0.0197	g. 0.0099	<2 μ
Colliery A.2 clod.. .. .	0.5	0.0093	0.0049	<2 μ
(Showing that air-elutriation to this grade merely "samples" the clod mass. Cf. Table LXII, p. 134.)				

TABLE CVI

Alkalinity of aqueous extracts

Sample.	Approximate pH.
Colliery A.3 clod	8.3
Colliery A.2 clod	8.4
Sericite-rich crust-and-film (Colliery A.2)	8.2

TABLE CVII

Base-exchange capacity

	B.E.	pH.
<i>Colliery A.3</i> : milled sample of clod	69	8.3
After one extraction with aq. diethylamine	B.E. falls to 50	
After four extractions	B.E. falls to 32	
Air-elutriated fraction <2 μ grade	58.6	7.9
Water-elutriated "fine fraction"	25	
<i>Colliery A.2</i> : milled sample of clod	33	8.4
Air-elutriated fraction <2 μ grade	34.4	8.0
Water-elutriated "fine fraction"	34	
<i>Colliery A.1</i> : Water-elutriated "fine fraction"	41	
<i>Colliery B.3</i> : Water-elutriated "fine fraction"	24	
<i>Colliery S.4</i> : Water-elutriated "fine fraction"	46	
<i>Minerals</i> :		
Quartz	Nil	
Kaolin	Nil to feeble ..	
Sericite (Colliery A.2 var.)	16.4	
*Montmorillonite in fuller's earth	88-122	
*Beidellite	107-120	

* Brammall, A. & Leech, J. G. C., *Geol. Mag.*, 1940, **77**, 102; Nagelschmidt, G., *Min. Mag.*, 1938, **25**, 140.

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APPENDIX II

THE COMPOSITION OF THE DUST IN THE RUN-OF-MINE COAL

By D. HICKS, M.Sc., A.I.C.

(*Officer-in-Charge, Coal Survey Laboratory, Cardiff*)

and

G. NAGELSCHMIDT, D.Phil.

(*Chemistry Department, Rothamsted Experimental Station, Harpenden, Herts*)

1.—Introduction

At an early stage of the inquiry into the environmental factors in chronic pulmonary disease in South Wales coalminers, it was desired to have comparatively large samples of dust from different collieries for animal experiments (of which the results will be published separately). One method of obtaining such dusts is to screen it from the run-of-mine coal—i.e., the coal as it comes direct from the working places. The dust so collected will not necessarily be of the same composition as the air-borne dust at the coalface, but it will be similar to this, as it will contribute largely to it. For a preliminary study such samples had the advantage of being easily obtainable under comparable conditions, unaffected by ventilation or other variables which might be encountered in the technique of obtaining samples of the air-borne dust. When, later in the inquiry, a number of large samples of air-borne dusts became available, the study of screened fractions of run-of-mine coal was discontinued. These, therefore, do not represent the full range of coals discussed in other parts of this symposium.

2.—Description of Samples

When the trams from the selected places arrived at the pithead, the large coal was carefully removed and then the small coal was screened by hand into a number of fractions. The coal of size smaller than $\frac{1}{4}$ -in. was reduced in bulk by mixing, coning and quartering, and afterwards brought to the laboratory, where it was screened into five fractions, namely $\frac{1}{8}$ -in.-72-mesh, 72-100-mesh, 100-240-mesh, 240-300-mesh and through-300-mesh B.S.* sieve. The last fraction was the dust used in the animal experiments, and forms the subject of this report. (The aperture of a 300-mesh B.S. sieve is 53 μ .)

Samples were taken at the following places:—

Colliery.	District.	Seam.
*A.1	Douglas	Lower Pumpquart.
*A.2	No. 5	Lower Pumpquart.
A.3	1	Stanlyd.
*A.3	2	Stanlyd.
A.8	West	Nine Feet.
*S.4	South	Two Feet Nine.

* Samples used for animal experiments.

3.—Screen Analysis and Percentage of Ash in Screened Fractions

The screen analyses in Table CVIII show that the size distribution of the $\frac{1}{8}$ -in.-0 material from all the sources is very similar, but that the percentage of the $\frac{1}{8}$ -in.-0 fraction in the coal from the trams is lowest in the high rank anthracites, A.1, A.2 and A.3, and highest in the low rank anthracite, A.8, and in the steam coal S.4.

It will be noted from the results given in Table CIX that the percentages of ash in the various screened fractions from any particular coal are very similar to each other, i.e. the coarse material has a similar ash content to the fine material. This applies generally to the full range of the sized grades. Moreover, the through-300-mesh fraction usually has an ash content similar to the fraction of size even as big as 2-1-in. It will thus be probable that the dust of respirable size would also contain a similar quantity of ash. The air-borne dust arising from the handling of the run-of-mine coal at the coalface will not necessarily be of the same composition as these samples, because there might be a selective action when the dust is raised.

The percentage of ash in the samples from different sources shows a wide variation, and in this selection it ranges between 4.2 and 23.5. There is no relationship between the rank of the coal and the ash content of the through-300-mesh fractions. Not only is there considerable variation from colliery to colliery, but there are also marked changes in the ash content of samples from different districts of the same seam at the same colliery—as, for example, at A.3, Districts 1 and 2, where the through-300-mesh fraction in the coal from District 1 contains 23.5 per cent. of ash, and that from District 2 only 12.7 per cent. These variations are not due to changes in the ash content of the coal itself, but mainly reflect changes in the section of the seam. In District 1, at the time of sampling, 7-12-in. of clod separated the main coal from the bed of coal above it, and 2-3-in. of rashes separated this from another layer of coal at the top of the seam. Between the top layer of coal and

* British Standard screens.

the roof there was also a variable thickness of clod, which was brought down at the face by the collier. The full section of the seam was mined, and in parts of the district the ground was disturbed, which also would contribute to a high ash content in the small coal. The considerable total thickness of clod is chiefly responsible for the high percentage of ash in the run-of-mine coal. In District 2 there was no clod and the seam consisted of 65-in. of coal, most of which had a fairly low ash content. The small coal in this district was contaminated only by rashes from a thin layer at the bottom of the seam and by a little of the cliff roof; thus, as would be expected, the raw smalls contained a comparatively low percentage of ash.

Mention should be made of the low ash content of the S.4 sample. The seam here consists of 5ft. of coal, containing only 2 per cent. of ash, with no intermediate layers of clod or rashes. There is little or no contamination from the hard fireclay floor, and the roof is ripped only in the roadways, this being a separate operation from coal-getting. The thin layer of bast at the top of the seam, which contains 33 per cent. of ash, parts readily from the remainder of the seam, and is stowed in the gobs.

The small coal from the Two Feet Nine seam in this and neighbouring takings is notably low in ash, and very much lower than the small coal from other seams in the Lower Coal Series in this area; the small coal from the latter varies in ash content from approximately 15 to 20 per cent. Because of this difference, caution must be exercised in generalising from S.4 for the steam coals as a whole.

3.—Chemical Analysis and Mineralogical Composition

The analyses of the ashes given in Table CX require no detailed comment. There is no striking contrast which can be correlated with change in rank of the coal or with the incidence of pneumokoniosis ("medical incidence").

The mineralogical composition has been calculated in the way described in Section F of this monograph, and the results are given in Tables CXI, CXII and CXIII. Table CXII also gives the X-ray diffraction data obtained from ash residues prepared by incinerating the dusts at 380° C.

The percentages of quartz in the dusts are in all instances low, namely, 2.4 or less. The dust with highest quartz content is that from A.1, a high incidence mine, but the quartz content of the dust from A.2, a low incidence mine, is the next highest in the series. The dusts from A.8 and S.4, medium and low incidence mines respectively, contain 0.4 per cent. of quartz, but that from District 2 of A.3, which is a high incidence mine, contains only 0.2 per cent. It may be said, therefore, that this selection of samples shows no relationship between the incidence of pneumokoniosis and the quartz content of the through-300-mesh fraction of the run-of-mine coal. This confirms the conclusions of Nagelschmidt (Section D) from analyses of samples of air-borne dust.

The proportions of different minerals, given in Table CXII, again show no regular change with rank of coal or medical incidence, although the percentage of quartz in the two highest rank anthracite samples, A.1 and A.2, is greater than in any of the others. The relative amounts of the major constituents—illite and kaolin—which together amount to 55–80 per cent. of the total minerals, also show no tendency to be related to rank of coal or medical incidence. It might be argued that the analyses of the through-300-mesh fractions could possibly be very different from that of the dust of respirable size. No experiments have been done to separate dust of respirable size from the through-300-mesh samples, but a comparison of the latter with the air-borne dusts at the coalface shows close similarity. Thus, the mean ash percentages and the proportions of siliceous minerals in the ash of the through-300-mesh samples and of the air-borne dusts from the same four anthracite mines were as follows:—

	Mean ash percentage.	Minerals per cent. ash.		
		Illite.	Kaolin.	Quartz.
Through-300-mesh samples ..	15	30	37	7
Air-borne dust samples	12	30	41	6

Three sized fractions bigger than the through-300-mesh have been analysed, and the calculated mineralogical compositions are given in Table XCIV. There is a slight decrease in the percentage of quartz, a marked decrease in the amount of illite, and a corresponding increase in the amount of kaolin, as the size of the dust decreases from $\frac{1}{2}$ in. to through-300-mesh. These changes might extend to the dust of respirable size, but the comparisons given above indicate that they would be unlikely to do so in marked degree. Indeed, the similarity of the through-300-mesh fractions and the air-borne dusts suggests the possibility of obtaining large samples of mine dust in a far simpler way than by the technique described on p. 96 of this monograph. The rock part of the air-borne dust—in so far as it is due to ripping as distinct from coal-getting—may, however, to some extent be lacking in such samples.

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Summary and Conclusions

1. Dust of size less than 300-mesh B.S. screens has been screened from run-of-mine coal from two anthracite collieries where the incidence of chronic pulmonary disease ("medical incidence") is high, and from one anthracite colliery and one steam coal colliery where the incidence is low.

2. Screen analyses suggest that the quantity of dust in the run-of-mine coal increases with decrease in the rank of the coal. The percentage of ash in the dust is similar to that in other screen fractions, and bears no apparent relation to the medical incidence nor to the rank of the coal. An example is given of markedly different ash contents in coal from different districts at the same colliery, explicable by differences in the seam section at the two places.

3. Kaolin, mica and carbonates were found to be the chief mineral constituents, with quartz amounting to 0.2-2.4 per cent. of the air-dried samples. Two of the high-rank anthracite samples contained the highest proportions of quartz, but one came from a high-incidence and the other from a low-incidence mine.

No other relationship is found between the chemical and X-ray diffraction analyses of the ash of the dusts and the medical incidence or the rank of the coal.

4. The average mineralogical composition of the through-300-mesh anthracite samples of run-of-mine coal is similar to that of the air-borne dusts at the coalface collected from the same mines.

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The chemical analyses have been done by Mr. W. N. Adams, of the Coal Survey Laboratory, Cardiff, and the authors wish to acknowledge his help in preparing this report for publication.

TABLE CVIII
Screen analysis of the coal of size $\frac{1}{8}$ -in.-0-in. in the run-of-mine coal
(Per cent. air-dried coal)

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
Medical incidence ..	High.	Low.	High.	High.	Medium.	Low.
$\frac{1}{8}$ -in.-0 fraction per cent. of coal in trams.	4.7	7.6	5.9	9.8	11.2	12.9
$\frac{1}{8}$ -in.-72-mesh B.S.S. per cent. of $\frac{1}{8}$ -in.-0.	75.2	74.2	78.5	72.4	77.0	77.8
72-100-mesh B.S.S. per cent. of $\frac{1}{8}$ -in.-0.	7.5	6.8	4.9	5.8	5.4	5.2
100-240-mesh B.S.S. per cent. of $\frac{1}{8}$ -in.-0.	7.1	9.3	8.9	11.2	8.9	9.1
240-300-mesh B.S.S. per cent. of $\frac{1}{8}$ -in.-0.	2.0	1.8	2.3	2.4	2.6	1.7
<300-mesh B.S.S. per cent. of $\frac{1}{8}$ -in.-0.	8.2	7.9	5.3	8.2	6.1	6.2

TABLE CIX
Ash in screened fractions
(Per cent. air-dried coal)

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
Medical incidence ..	High.	Low.	High.	High.	Medium.	Low.
$\frac{1}{8}$ -in.-0	16.0	13.6	21.8	11.6	13.8	4.8
$\frac{1}{8}$ -in.-72-mesh B.S.S. ..	16.1	14.0	21.7	11.8	14.1	4.9
72-100-mesh B.S.S. ..	15.4	12.1	22.0	10.7	13.3	4.2
100-240-mesh B.S.S. ..	14.9	11.4	21.9	10.2	12.8	4.2
240-300-mesh B.S.S. ..	14.2	12.3	22.3	10.6	12.3	4.8
<300-mesh B.S.S. ..	16.4	14.3	23.5	12.7	12.8	5.5

TABLE CX

Analyses of the ash of through-300-mesh B.S. screen fractions of run-of-mine coal

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
<i>Medical Incidence</i> ..	<i>High.</i>	<i>Low.</i>	<i>High.</i>	<i>High.</i>	<i>Medium.</i>	<i>Low.</i>
Ash, per cent. air-dried coal ..	16.36	14.30	23.47	12.72	12.82	5.45
CO ₂ , per cent. air-dried coal ..	2.03	1.45	2.05	1.23	0.66	0.32
Sulphate sulphur, per cent. air-dried coal.	0.01	0.01	0.04	0.06	0.03	Trace
Pyritic sulphur, per cent. air-dried coal.	0.04	0.04	0.27	0.61	0.14	Trace
<i>Per cent. of ash—</i>						
SiO ₂	43.48	42.15	42.66	36.91	45.64	48.18
TiO ₂	0.72	0.64	0.68	0.54	0.80	0.86
Al ₂ O ₃	22.14	25.23	29.34	28.18	33.21	31.72
Fe ₂ O ₃	10.53	10.20	5.22	9.11	4.98	7.24
CaO	8.41	7.03	11.27	11.43	4.30	0.66
BaO	Nil	Nil	Nil	0.02	0.02	Trace
MgO	4.13	3.68	1.90	2.26	1.99	2.57
K ₂ O	1.86	1.86	1.95	1.38	2.60	1.89
Na ₂ O	1.19	1.50	1.15	0.59	0.91	0.71
SO ₂	6.66	7.20	3.40	7.10	3.20	4.11
P ₂ O ₅	0.29	0.50	0.79	0.60	1.02	0.98
Loss on ignition at 800° C. . .	0.45	0.29	2.23	2.53	1.17	0.64
Total	99.86	100.28	100.59	100.65	99.84	99.56

TABLE CXI

Calculated mineralogical composition of the through-300-mesh B.S. screen fraction

(Per cent. of air-dried coal)

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
<i>Medical Incidence</i> ..	<i>High.</i>	<i>Low.</i>	<i>High.</i>	<i>High.</i>	<i>Medium.</i>	<i>Low.</i>
Illite	5.2	4.5	7.8	3.0	5.6	1.7
Kaolin	5.1	5.6	11.4	6.8	6.4	3.0
Quartz	2.4	1.4	1.2	0.2	0.4	0.4
Pyrite	0.1	0.1	0.5	1.1	0.3	Trace
Iron carbonate	1.0	0.7	Nil	0.1	0.5	0.5
Calcium carbonate	2.3	1.6	4.2	2.2	0.6	Nil
Magnesium carbonate	1.2	0.9	0.7	0.5	0.3	0.2
Calcium sulphate	0.1	0.1	0.2	0.4	0.2	Trace
Apatite	0.1	0.2	0.4	0.2	0.3	0.1
Rutile	0.1	0.1	0.1	0.1	0.1	Trace
Fe ₂ O ₃ (unaccounted for)	0.9	0.8	0.7	0.3	Nil	Nil
Na ₂ O (unaccounted for)	0.1	0.2	0.2	0.1	0.1	Trace
Total	18.6	16.2	27.4	15.0	14.8	5.9

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TABLE CXII

Composition of mineral matter in the through-300-mesh B.S. screen fraction
(Per cent. of total minerals)

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
<i>Medical Incidence</i> ..	<i>High.</i>	<i>Low.</i>	<i>High.</i>	<i>High.</i>	<i>Medium.</i>	<i>Low.</i>
Illite	28.0	27.8	28.5	20.0	37.8	28.3
Kaolin	27.4	34.6	41.6	45.3	43.2	49.2
Quartz	12.9	8.6	4.4	1.3	2.7	7.2
Pyrite	0.5	0.6	1.8	7.3	2.0	Trace
Iron carbonate ..	5.4	4.3	Nil	0.7	3.4	8.3
Calcium carbonate ..	12.4	9.9	15.3	14.7	4.0	Nil
Magnesium carbonate ..	6.5	5.6	2.6	3.3	2.0	3.9
Calcium sulphate ..	0.5	0.6	0.7	2.7	1.4	Trace
Apatite	0.5	1.2	1.5	1.3	2.0	2.1
Rutile	0.5	0.6	0.4	0.7	0.7	0.7
Fe ₂ O ₃ (unaccounted for) ..	4.8	4.9	2.6	2.0	Nil	Nil
Na ₂ O (unaccounted for) ..	0.5	1.2	0.7	0.7	0.7	0.3
Total	99.9	99.9	100.1	100.0	99.9	100.0
<i>X-ray Diffraction Analysis of Ash prepared at 380° C.—</i>						
Mica	Low-medium.	Low-medium.	Low-medium.	Low-medium.	ND	Low-medium.
Kaolin	High	High	High	High	ND	High
Quartz	Medium	Medium	Low	Very low	ND	Medium
Calcite	—	—	Medium	Medium	ND	—
Ankerite	High	High	—	—	ND	Low

TABLE CXIII

Through-300-mesh fraction
Per cent. of minerals containing SiO₂, Al₂O₃, K₂O and Na₂O

Colliery ..	A.1.	A.2.	A.3.		A.8.	S.4.
			Dist. 1.	Dist. 2.		
<i>Medical Incidence</i> ..	<i>High.</i>	<i>Low.</i>	<i>High.</i>	<i>High.</i>	<i>Medium.</i>	<i>Low.</i>
Illite	40	39	38	30	45	33
Kaolin	40	48	55	68	51	58
Quartz	19	12	6	2	3	8
Na ₂ O	1	1	1	<1	1	<1
	100	100	100	100	100	99

TABLE CXIV

Sized fractions in run-of-mine coal from colliery A.3, District 2
Per cent. of minerals containing SiO₂, Al₂O₃, K₂O and Na₂O

Size of Fraction.*	$\frac{1}{8}$ -in.- $\frac{1}{4}$ -in.	$\frac{1}{16}$ -in.-72-mesh.	100-240-mesh.	Through-300-mesh.
Illite	65	61	41	30
Kaolin	30	34	57	68
Quartz	4	4	1	2
Na ₂ O	1	1	1	< 1
	100	100	100	100

* British Standard screens.

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