

# SILICOTIC LUNGS: THE MINERALS THEY CONTAIN.

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## I. INTRODUCTION.

DURING the last eighteen months the author has had occasion to visit a number of collieries in the anthracite district of the South Wales Coalfield with the object of collecting, from the former working places of underground employees who had contracted silicosis in the course of their employment, samples of rock which could be proved to come under the category of "Silica Rock" as defined in English law, for the purpose of compensation under the Silicosis Schemes<sup>1</sup>.

<sup>1</sup> The part of the Silicosis Scheme applicable to the majority of underground workers in collieries (those engaged in sinking pits, driving cross-measure drifts, or in narrow working places come under a special part of the scheme) is as follows:

"This Scheme (No. 342 of 1931) shall apply to all workmen employed at any time on or after the commencement of this Scheme in any of the following processes:

(i) Mining and quarrying of silica rock: For the purposes of this Scheme silica rock means quartz, quartzite, sandstone, gritstone, or chert, but does not include natural sand or rotten rock.

(ii) Drilling and blasting in silica rock, in or incidental to the mining or quarrying of other minerals."

In a previous Order (No. 975) the latter part of (i) read "but does not include natural sand or rotten rock or any rock containing less than 50 per cent. free silica."

In the majority of cases, samples of rock that fulfilled this legal definition could be found, but in some, even when post-mortem examination had revealed silicosis and where the former working places of the deceased were accessible, it was not possible to find rock of the type included in the schemes. These cases naturally aroused the author's interest, for they appeared to make clear the possibility that rocks other than those included in the schemes could give rise to dangerous dusts: it was obviously a matter that required investigation.

With this in mind he had the privilege in August, 1932, during the meetings in London of the British Medical Association, of examining under the petrological microscope the series of excellent sections of silicotic lungs displayed by Dr C. L. Sutherland and Prof. S. L. Cummins. He was able to detect the presence of minute mineral particles in several of these slides, but as the sections had been stained for examination under the biological microscope, he came to the conclusion that the best material for his investigations would be the mineral residues obtained from silicotic lungs after the organic material had been removed. For this purpose Dr Sutherland kindly supplied him with four silicotic lungs of workmen who had been employed in three different processes in the pottery industry, and later Prof. S. L. Cummins and Dr A. F. Sladden sent many lungs, or parts of lungs, mainly of workmen who had been employed in the South Wales collieries. Dr E. L. Middleton supplied parts of the lung of an asbestos worker, and Prof. E. H. Kettle gave lung material of several employees who had been engaged in various industries.

The object of the present paper is not to deal in detail with each mineral residue obtained from all the lungs, some of which were not silicotic, investigated by the author; it is, on the contrary, to give the general conclusions to which he has been led inexorably by the petrological examination, supported by chemical analyses, of the mineral residues obtained in particular from the silicotic and silico-tuberculous lungs. The reason for this is that the author has been advised by some of the most eminent authorities on pulmonary diseases in this country to publish at this stage these general conclusions, leaving the detailed descriptions of the individual residues for a later occasion. As these conclusions differ so radically from those hitherto accepted relative to the minerals present in silicotic lungs, it becomes incumbent to describe the methods of obtaining the residues clearly and in such detail that they can be repeated by anyone who wishes either to question or to confirm these conclusions. Fortunately, no elaborate or special apparatus is necessary; acid, a few beakers and filtering apparatus, together with a petrological microscope, are the only essentials.

It will help to make this paper clear if, at this point, a brief outline is given of the main difference between the author's conclusions and those hitherto accepted. A review of the history of silicosis is not here necessary; suffice it to state that silica in an uncombined state has been universally accepted as the cause of the disease, which was hence named "silicosis." At the International Congress on Silicosis, held at Johannesburg in August, 1930, the definition

accepted at the final sittings was that silicosis is a "pathological condition of the lungs due to the inhalation of silicon dioxide," and that to produce this pathological condition "silica must reach the lungs in a chemically uncombined state<sup>1</sup>." The author's conclusion, on the contrary, is that in all the mineral residues of silicotic lungs examined by him, most of the material is not uncombined silica, but consists of minerals in which silica is in combination with other elements to form silicates; and in particular, the hydrated silicate of aluminium and potassium, sericite, a mineral which belongs to the mica family and is abundantly present both in the mineral residues of the silicotic lungs and also in the rocks and materials which gave rise to the inhaled dust. It is noteworthy to add that it was after he had found this "secondary white mica," as sericite is sometimes named, in the residues, that he turned to the rocks and materials to find it abundantly present in all those that had given rise to dusts that had been proved to produce silicosis.

Facts will also be submitted to show that the conclusions here reached receive marked support from the study of the chemical analyses of the ash of silicotic lungs carried out by earlier workers who, however, by omitting to interpret their analyses by allocating certain constituents to their mineral species, failed to realise that much of the silica returned in the analyses was actually present in the lung not as free silica, but in combination as silicate minerals.

The results of these investigations are based on the examination of the mineral residues obtained from 29 lungs<sup>2</sup>, each lung being from a person whose death had been certified as due to silicosis or silico-tuberculosis. Five of these were from workmen employed in the pottery industry as follows: 2 earthenware biscuit placers, 1 china turner, 1 china biscuit placer, 1 jigger; 21 were from underground workers in collieries of whom 6 were hard-heading workers, 11 colliers, 1 collier and sinker, 2 colliery repairers and 1 colliery labourer. The remainder were from 1 stone mason, 1 stone dresser, and 1 silica-brick worker.

## II. METHOD EMPLOYED FOR OBTAINING THE MINERAL RESIDUES FREE FROM ORGANIC MATERIAL.

Many of the lungs, or parts of lungs, were supplied preserved in formalin, some in glycerine; that of the asbestos worker in Kaiserling's preservative; and others were in the form of oven-dried material. All these were found suitable for the extraction of their mineral residues.

The lung material supplied in preservative is first well washed, and when a whole lung or almost the whole of a lung is being treated, it is transferred to a beaker of at least 2 litres capacity and so adjusted that only a small portion

<sup>1</sup> "Silicosis": *Records of the International Conference at Johannesburg 13-17 August, 1930*, p. 86.

<sup>2</sup> Forty-eight lungs have so far been treated and the residues examined; some of these were from workers who had died of pulmonary diseases other than silicosis, and one was a normal lung used as control.

of the lung rests at the bottom of the beaker<sup>1</sup>. 120 c.c. of strong nitric acid is poured into the beaker, and after a period of not less than 6 hours a further 120 c.c. of the same acid is added; additions of acid are repeated at intervals until the whole lung is slimed. The gradual disintegration of the portion of the lung resting on the bottom of the beaker causes the lung to collapse slowly into the acid, and it is found, with this quantity of acid, that bubbles with some carbonised lung material do not rise too high in the beaker. The time taken for the whole of a silicotic lung to become slimed by this process varies from 7 to 10 days, but even at the end of this period a few small fragments of the harder lung material may not be completely slimed. These partly slimed fragments, after decanting, and after comminution by probing each fragment with a glass rod, are treated with the same acid and become slimed in a few hours. This slime is then added to the decanted portion.

Lungs supplied as oven-dried material are treated by the same method, except that there is no preliminary washing. The action is, however, far more vigorous, and it is advisable to add small quantities of the dried material to the acid rather than the acid to the material.

When carrying out this sliming process of either a lung supplied in preservative, or as oven-dried material, especially for quantitative work, it is necessary to avoid so far as possible the deposition on the sides of the beaker of slime from acid bubbles rising above the level of the acid, for it will dry and be difficult to remove with acid or with water. By pouring a little acid down the sides of the beaker, soon after the bubbles have subsided, the sides can be kept clean.

The slime is now poured in portions of 50 c.c. into 500 c.c. or thereabouts of hot water, and after being well stirred the whole is filtered. For reasons given on p. 311 Whatman's No. 54 filter paper is recommended for this purpose. The residue is removed from the filter paper, is again well stirred in a large quantity of hot water, filtered and washed until free from acid, removed from the filter paper, and placed in a drying oven. The dried material is then transferred to a platinum dish and gently heated in a fume cupboard. Care should be taken during this stage that the fumes evolved do not come in contact with the Bunsen flame, for they are inflammable. After a period of 4-5 hours, when fumes are no longer evolved, the material is ignited in the usual way. The mineral residue thus obtained is light grey, or pale pinkish to reddish brown in colour, and in some cases may be a non-coherent powder, whereas in other cases, particularly in that of residues obtained from silicotic lungs of underground workers in collieries, it may be in slightly coherent aggregates.

It will be noted in the foregoing account that the filter paper is not ashed with the residue. The reason is interesting. Experiments conducted by Mr Bracewell of this Department and the author, showed that the ash of filter paper, even after prolonged ignition, shows under the petrological microscope

<sup>1</sup> A beaker of 2 litres capacity, measuring 19 cm. in length and 14 cm. in diameter, is very suitable for this purpose.

the presence of minute fibres of cellulose that are anisotropic, and although these can be distinguished easily by the particular nature of their polarisation colours from the mineral fibres occurring in the mineral residues of silicotic lungs, referred to later, it is advisable to obtain the residues entirely free from fibres derived from the filter paper. To avoid also the possible presence of even a few isolated fibres of the filter paper which may be released when the residue is washed, Whatman's No. 54, which has a smooth surface unlike the usual filter paper, is recommended.

Strong nitric acid is used for sliming the lung material because it is less likely to attack<sup>1</sup> the silicate minerals present than strong hydrochloric acid; and it is considerably quicker in its sliming effect than either hydrochloric or sulphuric acid, particularly than the latter. Moreover, filtration is far easier after nitric than after sulphuric acid treatment. The oxidising effect of nitric acid on any iron present in the residues gives various reddish or reddish brown tints, which, when a number of residues are dealt with, assume a significance to the investigator. The coalminers' lungs treated by the author, for example, gave different coloured residues comparable to the different coloured ashes of various coals; and there are also interesting colour differences in the residues of underground workers from different localities. Another advantage of using nitric acid is that the acid fumes envelop the whole of the lung material during the process and thus obviate unpleasant odours.

Hydrochloric acid was used for some of the oven-dried material, and sulphuric for a silicotic lung preserved in formalin. The mineral residues obtained with these two acids are similar in every way to those obtained with nitric acid treatment, except in colour, that after sulphuric acid treatment being white.

The carbonates of calcium, magnesium, etc., would not be present as minerals in the residues after the acid treatment. Such minerals, when present at all, were in very subordinate amounts in the silicotic lungs hitherto treated; the analyses of the residues prove this from their low content of lime and magnesia.

It is of interest to add that the mineral residues can also be obtained from the slimed material without ignition by agitating the slime in water, and allowing the minerals to settle. This is not recommended except as a means of showing conclusively that the ignition does not result in the formation of new minerals.

<sup>1</sup> Analysis of the whole filtrate from the acid treatment of lung A was made in order to determine the amount of each constituent leached by the acid. The filtrate gave the following weights in grams:  $\text{SiO}_2$  0.048,  $\text{Al}_2\text{O}_3$  0.057,  $\text{Fe}_2\text{O}_3$  0.264,  $\text{CaO}$  0.254,  $\text{MgO}$  0.077,  $\text{K}_2\text{O}$  0.798,  $\text{Na}_2\text{O}$  0.488,  $\text{P}_2\text{O}_5$  1.187,  $\text{MnO}$  0.005. By calculation it is found that the total silica leached by the acid is only 1.6 per cent. of the silica content of the residue; similarly, 4.3 per cent. of the total alumina was leached.

### III. EXAMINATION OF THE MINERAL RESIDUES UNDER THE PETROLOGICAL MICROSCOPE.

The mineral residues, which are markedly reddish brown in colour as the result of the presence of iron in the ferric state after the nitric acid treatment, are boiled in hydrochloric acid to remove most of the colour. This is not essential but helps to bring into prominence the minerals under polarised light.

Before mounting the residue in Canada balsam it is advisable to remove the light ash from the minerals, especially in the case of residues from the silicotic lungs of underground workers in collieries, for these contain a good deal of ash from the dust of coal and other carbonaceous material. This removal is effected by placing the residue in a mixture of bromoform (sp. gr. 2.89) and benzene (sp. gr. 0.88) made up to a specific gravity of 2. Liquid of this density is chosen because the number of minerals (about 20 or so) that have a specific gravity of under 2 are soluble in water; the few remaining minerals in the list, such as different kinds of coal, would if present in the lung be in the form of ash in the ignited residue. The minerals sink to the bottom of a Sollas separator, whence they are easily removed, washed with benzene and afterwards with alcohol, dried and set in Canada balsam in the usual way that fine particles of minerals are mounted for microscopic examination.

In Ordinary light (that is, light which is not polarised) under a magnification of 30 diameters the mineral residue appears as a number of pale greyish to slightly reddish brown small aggregates, for it is not possible, during mounting, to keep the minerals as separate individuals. Under higher magnification, again in Ordinary light, it is only the faint outlines of crystals that can be seen; no mineral species can be recognised under this light. A number of dark specks may be visible if the ignition of the carbonaceous material has not been quite complete.

In polarised light, however, with the nicol prisms crossed<sup>1</sup> and using a substage condenser and a good source of light (100-watt gas-filled translucent electric bulb is very suitable) the material is seen to be anisotropic (Pl. VI, Fig. 1). Under a magnification of 200 diameters (still better with higher magnification) the aggregates are clearly seen to consist mainly of thousands of minute fibrous crystals. There are also present many small irregular-shaped grains of quartz, some large grains of that mineral, and in the case of some of

<sup>1</sup> It has been suggested that as some of the readers may not be familiar with the petrological microscope, an explanatory note here would be useful. The most distinctive features of the petrological microscope are the Analyser and Polariser (the nicol prisms) each of which is constructed so as to allow the passage of one ray vibrating in one plane (polarised light) and to eliminate the other vibrating at right angles to it. When the nicol prisms are crossed there is total darkness unless the object is doubly refracting. When, for example, a section of a lung containing minute colourless crystals of an anisotropic mineral is examined in Ordinary light (as under a biological microscope) the crystals are not visible. Under crossed nicols there is total darkness *except* where the minerals occur; these will show up clearly, and by slight rotation of the Analyser or Polariser the exact location of the minerals, in relation to the lung tissue, can be determined.

the residues, occasional crystals of other minerals to which reference is made in a later part of this paper.

The outstanding fact should be emphasised that in all the mineral residues of these silicotic lungs there are countless mineral fibres, hundreds of which are present for every grain of quartz that can be recognised. The identity of these fibres now calls for consideration.

That they are fibres, and not minute scaly plates viewed end on, is easily demonstrable for they are seen to cross under one another in various directions, like a piled-up bundle of needles, as each successive layer of fibres in the aggregates is brought to focus. This adjustment of the focus from top to bottom of the felted aggregates brings out in a striking manner the fibrous nature of the bulk of the mineral residue; it points also to the difficulty of photographing them under high power, for only a limited number can be brought into sharp focus at one time. Fig. 2 is a photomicrograph, taken under crossed nicols, of some of the longer fibres, the points of light in the aggregate representing, for the most part, minute fibres just out of focus.

The fibres are of a form not assumed by quartz, no matter how finely that mineral is powdered. Some quartz grains were isolated from a sandstone that had proved, in the Great Mountain Colliery in the anthracite district of South Wales, to have given rise to a number of cases of silicosis. The quartz grains were then finely powdered and examined microscopically. Fig. 3 is a photomicrograph, under polarised light, of the fine powder; it will be seen that none of the particles, even the finest, displays a fibrous form; in fact, quartz does not break into fine fibres. The cleavage of forms of free silica other than quartz need not be discussed here; chalcedony, agate, opal, flint, chert, etc., are not present in the mineral residues of silicotic lungs that have so far been examined by the author, and they are absent also from the rocks which gave rise to the inhaled dust in these cases.

Many of the fibres are not straight but are bent towards their sharper ends, testifying that they are flexible (Fig. 1, in text); many show parting along their lengths, thus expressing their fibrous nature. The great majority are from 0.5 to 2 microns in length; they are from 4 to 10 times as long as they are broad, and vary in thickness from about 0.1 to 0.5 micron. Occasional longer fibres, such as those shown in Fig. 2, are present. It is hoped at a future date to give details about the physical and optical characters of these fibres in a mineralogical publication. Suffice it to state here that from their form, cleavage, specific gravity, refractive index, birefringence and optic orientation, they prove to be fibres of the mineral, sericite. The "Sensitive Tint" plate employed for determining their optic sign is useful also, it is interesting to note, for showing up the fibres, for those in one direction are pale yellow, and those at right angles to that direction are pale blue.

The bulk of all the mineral residues of the silicotic lungs examined in the course of those investigations consist, therefore, of myriads of minute acicular fibres of sericite, many small grains of quartz and some larger grains of that

mineral from 5 to 10 microns in length. Minute scales of sericite are also present, and in some of the residues from underground workers, minute needles of rutile, but these and other minerals present form so small a proportion of the residues that they need not be further considered in a paper which is not written for mineralogists but for those specially interested in silicosis and in the rocks which give rise to that disease.

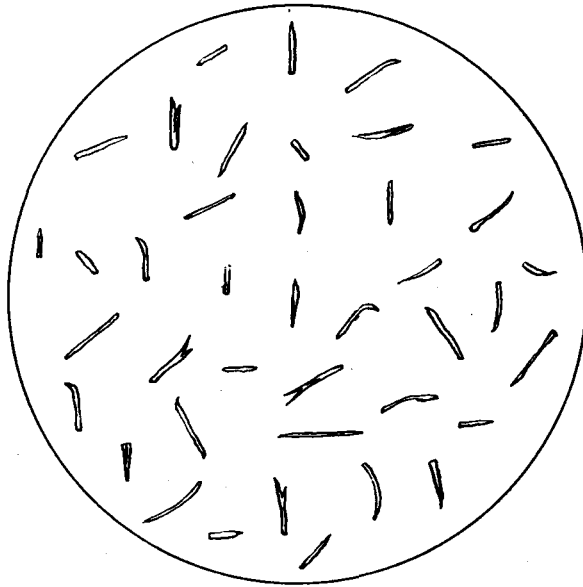


Fig. I. Sketch to illustrate the form, as seen under 1/12 in. oil-immersion objective, of fibres of sericite in the various residues obtained from silicotic lungs. The longest fibres, few in number, are 5 microns in length; the great majority are under 2 microns in length.

#### IV. SERICITE: ITS CHEMICAL AND PHYSICAL CHARACTERS AND MODE OF OCCURRENCE.

Sericite, sometimes called "secondary white mica," is a hydrous silicate of aluminium and potassium containing, according to the analysis of Shannon<sup>1</sup> of specially selected pure material, 46.58 per cent.  $\text{SiO}_2$ , 37.46 per cent.  $\text{Al}_2\text{O}_3$ , 0.80 per cent.  $\text{Fe}_2\text{O}_3$ , trace of  $\text{CaO}$ , 1.16 per cent.  $\text{M}_2\text{O}$ , 6.38 per cent.  $\text{K}_2\text{O}$ , 0.64 per cent.  $\text{Na}_2\text{O}$ , 6.06 per cent. of water above  $110^\circ\text{C}$ . and 0.30 per cent. water below  $110^\circ\text{C}$ .

It belongs to the mica group of minerals and is related to muscovite, but differs chemically from that mineral in having a lower content of potash and a higher content of water (muscovite contains 45.2 per cent.  $\text{SiO}_2$ , 38.5 per cent.  $\text{Al}_2\text{O}_3$ , 11.8 per cent.  $\text{K}_2\text{O}$  and 4.5 per cent. water). Unlike muscovite, which occurs in relatively large platy crystals and scales and not as minute fibrous aggregates, sericite is present in rocks in two forms, as minute scales and as

<sup>1</sup> Shannon, E. V. (1926). *The Minerals of Idaho, U.S. Nat. Mus. Bull. No. 131*, p. 273.



minute fibrous aggregates. This is a very important physical difference between these two minerals affecting their lung-penetrating power, for whereas sericite is present in many sandstones, sandy shales, quartz conglomerates, etc., and certain igneous rocks, in a form and of a size that enable it to enter the alveoli, muscovite is in platy crystals which, although easily cleaved, yet remain as thin but relatively large scales that are likely to have much less lung-penetrating power than the minute fibres of sericite. An analogy here may be permissible. Muscovite can be compared, in its physical form, to thin but wide boards of pine-wood and the acicular fibrous aggregates of sericite to pine-needles. Hence it is obvious that the presence of muscovite or certain other micaceous minerals does not confer upon the dust of such rocks a lung-penetrating power; similarly with the particles released in the mica industry.

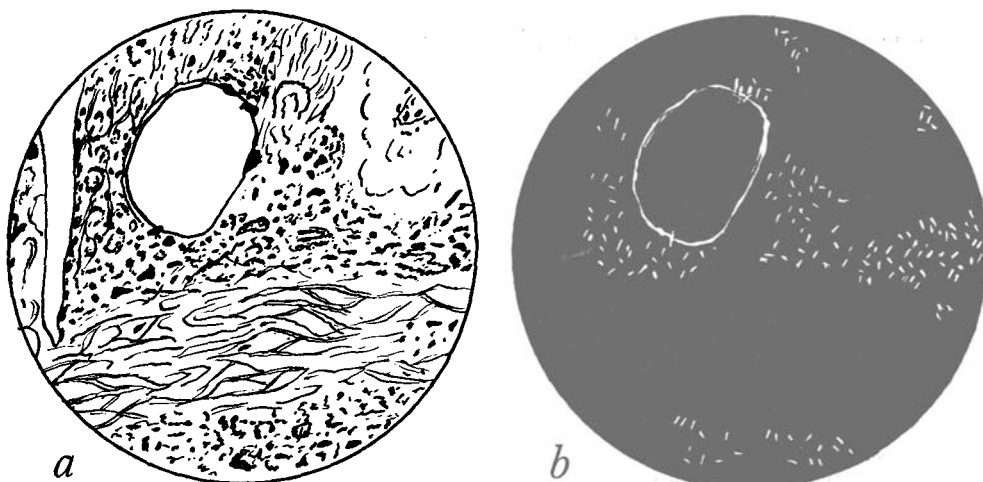


Fig. II. (a) Sketch of a microscope section from near the root of a silicotic lung of a collier. To the extreme left, a part of the bronchial cartilage is just in the field.

(b) Sketch of section (a) as seen under polarised light, to show the distribution of sericite fibres. The large oval outline, not seen under polarised light, has been inserted as a location mark. The size of the fibres (but not their number) has been exaggerated for purpose of reproduction. The majority of the fibres are from 0.5 to 1.5 microns in length.

In most, if not in all, of the rocks in which sericite occurs, the mineral is of secondary origin, that is, it has been formed by the alteration of other minerals subsequent to the formation or during the further induration of the containing rock. Details of the processes which give rise to sericite need not be discussed in this paper, but there is one point of extreme interest, the importance of which will be emphasised when a comparison is made hereafter between sandstones that have proved to have given rise to many cases of silicosis and sandstones that have been worked for a long period of years without having caused a single case of that disease. The point is that certain minerals, notably potash feldspars, under certain conditions of pressure, temperature, and other factors, become sericitised, that is, they change from their original form of

felspar to become minute scales and minute aggregates of acicular fibres of sericite; this sericitisation of felspar (Fig. 4) is a well-known process in petrology. Now these acicular fibres are only loosely held together in the body of the rock so that during the impact of drilling or blasting they are readily freed into the surrounding atmosphere<sup>1</sup>. Moreover, be it noted, they are of a size and form which enable them to enter the alveoli, as is shown when sections of silicotic lungs are examined under the petrological microscope (Text-fig. II *a* and *b*, p. 315).

Sericite is most common in rocks which also contain a high percentage of free silica in the form of quartz; it is not, however, present in all rocks that contain quartz. It will presently be shown that it is the dust from the former rocks, namely, from those that contain abundant sericite as aggregates of acicular fibres, that has been proved to cause silicosis; and that the dust from those which contain no sericite, or only occasional crystals of it, but which do contain a very high percentage of quartz, as high and higher than the rocks that have proved dangerous, has never given rise to a single authenticated case of silicosis.

#### V. CHEMICAL ANALYSES OF THE ASH AND OF THE MINERAL RESIDUES OF SILICOTIC LUNGS.

So far as the author has been able to ascertain in the British and foreign literature on silicosis to which he has had access, all the published analyses relating to silicotic lungs have been made on the ash obtained from the dried lungs; in no case is there a reference to the analysis of the mineral residue of a silicotic lung from which organic salts have first been removed. The published analyses show, therefore, a high percentage of constituents such as phosphoric oxide, sodium oxide, etc., which are shown also in the analyses of the ash of a normal lung. The presence of a high content of salts of phosphorus adds considerably, according to well-known chemists, to the difficulty of analysing small quantities of material, particularly for their content of alumina.

As preliminary to the interpretation of these analyses, one point is of such great importance that special reference must be made to it here; it is concerned with the content of alumina shown in all these analyses. In sandstone, sandy shales, quartz conglomerates and all the other rocks, the dust of which have given rise to silicosis, aluminium does not occur as alumina; it is present in those rocks in combination with silica and generally with alkalis. It is true that in some shales and clays a very small amount, a fraction of 1 per cent., of free alumina may be present, and that the amount is very considerable in bauxite and some laterites, but these are rocks of limited distribution. The fact of importance here is that in the analyses of the ash of silicotic lungs, as also in the analyses of the mineral residues carried out for the author, the alumina shown in the analyses was present in the minerals not as alumina, but as a silicate of alumina. To interpret, therefore, these analyses it is essential to

<sup>1</sup> This is easily demonstrated. By breaking a piece of the Transvaal "Banket," or of a sericitic sandstone, the fibres released into the atmosphere can be collected on a gelatine plate.

allocate all the alumina to aluminium silicates or to hydrated aluminium and potassium silicates known to be present in the rocks which gave rise to the inhaled dusts.

(a) *Analyses of the ash of silicotic lungs.*

The earliest analysis of the ash of a silicotic lung to which reference has been seen is that by Church<sup>1</sup> in 1889. It gives: silica 47.78 per cent., alumina 18.63 per cent., the rest consisting of iron oxides, alkalies, phosphates, etc. Now the 18.63 per cent. alumina demands a certain percentage of silica depending on the mineral in which the aluminium was present. In this case it was the ash of a potter's lung, and as the material the deceased handled contained a good deal of sericite, as explained in the previous paragraph, the alumina content will be allocated to that mineral<sup>2</sup>. Hence, 18.62 per cent. alumina demands 23.28 per cent. silica, 2.67 per cent. potash from the alkalies, and 2.68 per cent. water, giving 47.66 per cent. sericite. The remaining silica, namely 47.78 minus 23.28, or 24.5 per cent., is, therefore, the maximum amount of free silica remaining; thus the amount of sericite present in the inhaled dust was almost double the amount of free silica.

Hodenpyl<sup>3</sup>, in 1899, found that the ash of the lung of a knife-grinder contained: silica 27.1 per cent., alumina 32.9 per cent., with various other constituents including 4.97 per cent. potash and 21.4 per cent. phosphoric oxide. Sericite is abundantly present in many natural grindstones. The interpretation of this analysis on the same lines as the previous one shows that there could be no free silica present at all; in fact, there is not sufficient silica present to satisfy the alumina, the probable explanation being that the analysis shows too low a content of silica, or too high alumina.

No useful purpose will be served in multiplying examples of analyses that lead to the same conclusion, but reference must be made to those given in the valuable paper<sup>4</sup> in 1913, by Dr John McCrae, Government Analyst, Transvaal, who made complete chemical analyses of the ash of six South African miners affected with miners' phthisis (silicosis) and of one normal lung. It will be sufficient here to deal with the analysis of the lung ash that showed the highest content of silica, and hence the analysis which, as it were, appears at first sight to militate most strongly against the conclusions here advanced.

The analysis given of the ash of this lung, No. 4, is as follows, the numbers expressing the percentages: silica 48.02, alumina 9.59, ferric oxide 8.49, lime 2.16, magnesia 1.64, soda 6.42, potash 6.07, phosphoric oxide 16.47, sulphuric oxide 0.36, chlorine 0.17.

The rock that was worked by these South African miners is the famous gold-bearing quartz conglomerate known in mining literature as "Banket."

<sup>1</sup> Church (1889). Milroy Lectures, *Lancet*, i, 615. The analysis was made for Dr Arlidge in 1875.

<sup>2</sup> The presence of other silicate minerals in clays used in the pottery industry is discussed on p. 320.

<sup>3</sup> Hodenpyl (1899). New York. *Med. Record*, 56, 942.

<sup>4</sup> McCrae (1913). The Ash of Silicotic Lungs, *S. Africa Inst. for Med. Research*, March 3rd.

The most common mineral in this rock other than quartz, is sericite. The rock is described on p. 323 and sections of it are shown in Pl. Figs. 5, 6 and Fig. III *a* in text.

Allocating to sericite the necessary silica, potash and water required by the 9.59 per cent. alumina shown in the analysis, the amount of sericite in the lung ash becomes 24.23 per cent. The silica remaining is 48.02 per cent. minus the 11.98 per cent. silica taken up in the sericite; that is, the remaining silica is 36.04 per cent. It does not follow that this remaining silica was all present in the form of free silica<sup>1</sup>, but let it be considered here to be all free silica. Hence the ratio of sericite to free silica in the lung ash is, approximately, as 2 is to 3.

A fact of the greatest possible importance now arises, namely, the relative

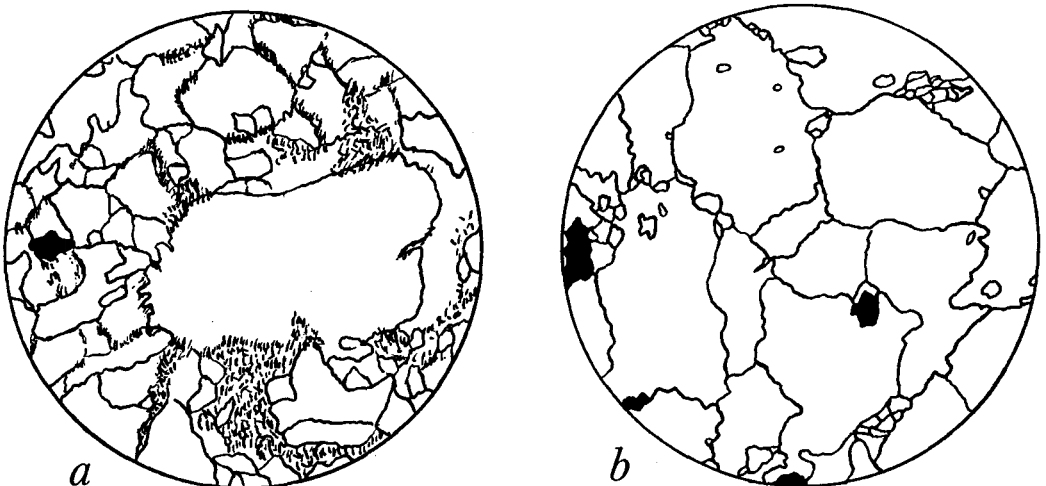


Fig. III. (*a*) Sketch of the microscope section of the Transvaal "Banket" shown in Fig. 5. The clear areas are quartz; the acicular aggregates are mostly sericite; the black patch is pyrite. (*b*) Sketch of the microscope section of the Kolar gold-bearing quartz shown in Fig. 7. The clear areas are quartz; the black patches are pyrite. No fibrous minerals occur between the interlocking quartz grains.

distribution in a silicotic lung of this free silica in the form of quartz, as compared to that of sericite. All the mineral residues of the silicotic lungs show the presence of a number of grains of quartz that are much larger than the largest fibres of sericite. Some of the quartz grains are 10 microns in diameter, 8 microns in breadth and 5 microns in thickness, but in the lung sections showing the alveoli, it is unusual to find a grain of any mineral larger than 2 microns in length. The conclusion is that the irregularly shaped grains of quartz larger than 2 microns in diameter (Fig. IV) did not enter the alveoli but were lodged in the bronchi and bronchioles of the lung.

One grain of quartz  $10 \times 8 \times 5$  microns has the same volume as 800 fibres of sericite 2 microns in length and 0.5 micron in width and thickness; and one

<sup>1</sup> Zircon and other aluminium-free silicates occur in the Banket.

such quartz grain contains over sixteen hundred times as much silica as one of the sericite fibres. Now a grain of quartz of the dimensions given would contribute, in a chemical analysis, an amount of silica equal to that contributed by 1630 fibres of sericite. Hence it would seem that a lung that contained more free silica than of sericite may not have been affected so much by the larger quartz grains in the bronchi and bronchioles as by the countless fibres of sericite in the alveoli. It is not suggested here that no quartz enters the alveoli; minute particles of it have been seen there, but for every grain of quartz in the alveoli there are scores of sericite fibres.

Strength is given to this argument by the valuable evidence adduced by Dr McCrae, who illustrates his paper with a diagram representing the size and form of the largest grain of quartz. The largest he found was 10·5 microns in

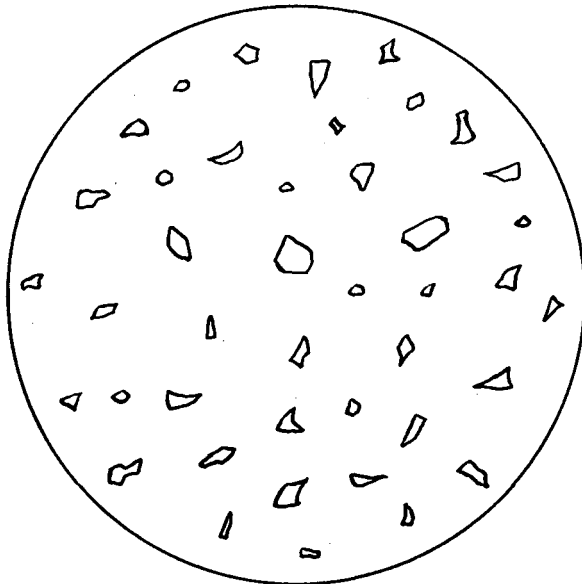


Fig. IV. Sketch to show the form of the coarser particles of quartz seen in the various residues from silicotic lungs. The largest particles are from 5 to 10 microns in diameter.

diameter. He states, however, that 70 per cent. of the whole material<sup>1</sup> was less than 1 micron in diameter. It is precisely this 70 per cent. of fine particles, it is contended here, that probably plays the chief rôle in the causation of silicosis.

It would seem, therefore, that chemical analyses of the ash of silicotic lungs support strongly the evidence revealed by the petrological microscope, namely, that the bulk of the finest mineral particles in a silicotic lung consist of minute fibres of silicate minerals; chiefly of sericite, in the cases examined by the author.

<sup>1</sup> Before examining this material under the microscope, Dr McCrae digested it with HCl and KClO<sub>3</sub>, thus decomposing most of the silicates, including sericite. What he examined, therefore, was not the residue but the particles of quartz and the remnants of the silicates which survived this harsh chemical treatment.

*(b) Analyses of mineral residues from silicotic lungs.*

The mineral residues from silicotic lungs, obtained by the method described on p. 309, differ from the ash of such lungs in that most of the organic constituents present in the ash have been removed from the former by acid treatment.

Complete chemical analyses of three of these mineral residues were carried out by Dr A. W. Groves at the Chemical Department of the Imperial College of Science and Technology; the expenses of this part of the research having been defrayed by the British Medical Research Council. These are given below:

	Mineral residue from lung A	Mineral residue from lung B	Mineral residue from lung C
SiO <sub>2</sub>	49.52	62.16	59.23
Al <sub>2</sub> O <sub>3</sub>	21.99	19.85	26.38
Fe <sub>2</sub> O <sub>3</sub>	3.55	3.30	2.03
FeO	—	0.19	0.11
CaO	Lost before weighing	0.90	0.45
MgO	1.73	0.84	0.62
K <sub>2</sub> O	2.47	3.83	5.28
Na <sub>2</sub> O	0.78	0.52	0.85
TiO <sub>2</sub>	0.08	0.64	0.78
P <sub>2</sub> O <sub>5</sub>	2.55	5.77	2.68
MnO	—	0.01	0.01
Water below 110° C.	2.18	0.51	0.33
Water 110° to 350° C.	10.37	0.20	0.26
Water above 350° C.	2.27	1.39	0.56
Total	97.49	100.11	99.57

Lung A was that of a man 66 years of age who had been engaged in the pottery industry for 50 years as earthenware hollow-ware jigger. Certified silicosis.

Lung B that of an underground colliery worker in the Swansea district, South Wales, employed as a hard-heading worker. Certified silico-tuberculosis.

Lung C that of a collier at Pontycymmer, South Wales, aged 51 years, who had also worked as a quarryman in North Wales. Certified silico-tuberculosis.

Under the petrological microscope these three residues were seen to consist mainly of minute acicular fibres of sericite, but in the residue from the potter's lung there was also found a little clay material which is composed of aluminium silicate.

Some of the alumina present in this residue should, therefore, rightly be allocated to kaolin<sup>1</sup> (SiO<sub>2</sub> 43.5 per cent., alumina 36.9 per cent., water 19.6 per cent.), but as the ratio of alumina to silica in this mineral is not appreciably different from the ratio in sericite, there is no necessity to enter here into complicated calculations which could influence the results only to a minor degree. The presence of this aluminium silicate explains, however, the lower potash content in relation to alumina in A than in B and C.

It should be explained also, before proceeding to the allocation of the constituents, that the water content was determined between 110 and 350 degrees, and above 350, as an additional proof that the fibrous mineral was not

<sup>1</sup> Other silicate minerals are also present in clays, but they need not be considered here because they would not affect the calculations except to an infinitesimal degree.

one of certain mineral constituents of clay which lose all their water at temperatures well below 350° C.; and that in the case of the residues from B and C, which contained before ignition a good deal of carbonaceous material, the ignition had to be prolonged at high temperature, with the consequent loss of much water of composition, before the residue was given for analysis.

Allocating, therefore, the alumina in these three residues to the requisite amounts of silica, potash and water to form sericite, the following results are obtained:

	A	B	C
	%	%	%
Sericite	55.83	51.01	59.48
Free silica	22.04	37.35	19.66

It will thus be seen that these chemical analyses when interpreted by the allocation to the alumina of the amount of silica it demands to form sericite (or indeed to form any aluminium silicate that could occur in the dusts inhaled by these workmen) support in a very striking manner the conclusions formed prior to these analyses from the examination of the same residues under the petrological microscope. And it is important to note that the few large grains of quartz in these residues, large relative to the sizes of the sericite fibres, contribute their quota of free silica in the analyses out of all proportion, as previously explained, to their probable silicotic effect in the lung whether as mechanical irritants in the tissue or as sources of chemical action.

The author submits, therefore, that the mineral residues obtained by him from silicotic lungs (and this applies to all those he has so far investigated) show definitely that it is not quartz, or any kind of free silica, that forms the bulk of these residues; and he suggests that silicosis is not mainly due to free silica, as has hitherto been accepted, but to silicate minerals occurring in the form of minute fibres loosely held together in the rocks so that, during handling, drilling and blasting, they are readily freed into the atmosphere and inhaled into the lungs.

#### VI. SILICA ROCKS: COMPARISON OF THOSE THAT CAUSE SILICOSIS WITH THOSE THAT DO NOT.

It is not proposed to deal here with all the rocks that are known to produce dust which causes silicosis; that will be done in a later paper in which will be considered also certain other materials used in industries which also cause this dread disease.

There are, however, in this and other countries some outstanding cases of rocks the dusts of which have been definitely proved to cause numerous cases of silicosis; there are, on the other hand, rocks very similar in their content of free silica and in the size and form of the quartz grains which have been worked extensively for long periods of years without causing a single authenticated case of silicosis. Some of these rocks will now be considered.

The gold-bearing quartz conglomerate ("Banket") of Transvaal, South

Africa, is one of the most notoriously dangerous rocks in this respect. "Up to October 1929, 7633 beneficiary miners were alive; 2271 of these were in the ante-primary stage of silicosis, 2306 in the primary stage, and 2814 in the secondary stage. There were 2014 widows and 3538 children in receipt of pensions. . . . The real cost of miners' phthisis was said to be £1,000,000 per year. The Government Actuary estimated the outstanding liability of the mines at £6,400,000<sup>1</sup>." This quartz conglomerate contains between 80 and 90 per cent. of free silica in the form of quartz; in this respect it is very similar to the gold-bearing quartz worked in the Kolar goldfield, India, which, however, actually contains a little more quartz (over 90 per cent.) than the "Banket." Whereas the dust of the South African rock has given rise to some thousands of cases of silicosis, no single case of that disease has been diagnosed in the Kolar goldfield where thousands of workmen have been employed over long periods of years and where the precautions enforced by law in the South African goldmines to prevent silicosis, such as the use of wet drilling to lay the dust, are not in force. The very process, namely, dry drilling with pneumatic drills, which proved so extremely dangerous in the South African mines, has been in operation for many years at Kolar, and is still in use in these goldmines, some of which are now worked to depths exceeding 6000 ft. If quartz is the cause of silicosis, why is it that with its 90 per cent. and more quartz, the gold-bearing rock at Kolar does not give rise to dangerous dust?

Two suggestions have been made to account for this hitherto puzzling fact: (1) that there may have been cases of silicosis at Kolar but not diagnosed, (2) that the rock adjacent to the gold-bearing quartz gives rise to dust that enables the inhaled quartz dust to be ejected from the lungs. It is sufficient here to state, relative to the first suggestion, that the workmen at Kolar are periodically examined under X-ray by medical experts who are actually on the lookout for cases of silicosis, but are unable to find any; and that the statistics relating to various diseases of workmen are as carefully kept at Kolar as they are in this or any other country<sup>2</sup>.

The suggestion about the nature of the dust of the "country rock," that is the rock forming the hanging-wall and footwall of the Kolar goldmines, was made in 1928 on the assumption that the shale-dust spread in collieries to prevent spontaneous combustion, when inhaled by workmen, enabled much of the quartz dust to be ejected from the lungs. On the statistics then available

<sup>1</sup> Statement by Mr Barry in the *Records of the International Conference on Silicosis* held at Johannesburg, August, 1930, p. 84.

<sup>2</sup> The total underground labour force at the four goldmines at Kolar is 12,000, of whom 300 are Europeans. The latter undergo periodic X-ray examination; the natives object to such examination. The present average length of underground service of the Europeans is over 15 years and a large number have over 20 years' service. Hundreds of natives are in receipt of gratuities paid by the Company for 20 and more years' service underground. The natives are employed underground throughout the year. Pulmonary diseases among the underground workmen are not more common than amongst the 6000 employed on the surface, and amongst those employed in industries in Bangalore. Reports of the Mysore Government show this.



relative to the incidence of silicosis in British collieries, this was a reasonable assumption, but it must be remembered that it was not until January, 1929, that the amended Silicosis Scheme became effective; previous to that date it was not possible for most underground workers in British collieries to establish a claim for compensation for silicosis, hence no reliable statistics were previously available. The author knows of a large number of silicotic cases contracted in collieries where shale dust is very pronounced: the hypothesis relative to the efficiency of this dust in preventing silicosis has now few adherents. Even if such dust had, however, proved effective in British collieries the very significant fact remains that no shales occur in the working places of the Kolar goldmines. A complete suite of the "country rocks" at Kolar are housed in our Geological Department; they have been examined by the author, and have been admirably described many years ago by Dr Smeeth, Sir Thomas Holland, Dr Maclaren and other geologists. These are hard crystalline rocks such as amphibolites and hornblende schists and are as unlike the shales of the coal-measures as rocks possibly could be in their dust-producing effect and in the nature of that dust. Moreover, the quartz veins worked for gold at Kolar are substantial veins varying in width from 2 to 5 ft. and more; in the mining operations thousands of holes are drilled in this quartz daily in every one of these large goldmines, employing a total labour force of 12,000 underground workers.

It is clear, therefore, that hitherto no acceptable explanation has been given why the inhaled dust of the South Africa quartz-bearing rock is so extremely dangerous in its silicotic effect, and why the dust of the Indian rock, with still more quartz, has not caused a single case of silicosis. The real explanation, it is here submitted, is simple: whereas in the South African rock there are, between the quartz pebbles and quartz grains, aggregates of minute acicular fibres of sericite, hundreds of which fibres can be seen in microscope sections of this rock, such acicular fibres are absent from the Kolar quartz rock or very rare. A reference to Figs. III *a* and *b* and to the photomicrographs of these two rocks (Figs. 5-7) makes this clear. The quartz grains in the Kolar rock are interlocking; there is no fibrous mineral to be seen between the sharp boundaries of the individual grains. Between the quartz pebbles and the quartz grains in the "Banket," acicular crystals of sericite are very abundant; in fact, sericite ranks next to quartz as the most common mineral in this South African rock. It is not suggested here that all the sericite present is in fibrous form; much of it is in the form of minute scales, but the point is that countless fibres of this mineral do occur throughout this rock.

Reference has already been made to the incidence of silicosis in some of the anthracite collieries in South Wales, and it will be of interest now to enquire why it is that silicosis is prevalent in some of the coalfields of Great Britain and entirely absent in others.

To avoid overburdening this paper, reference will be confined for the present to certain dangerous rocks in the anthracite district of South Wales, where silicosis is very prevalent, and these will be compared with similar rocks in the

Scottish coalfields where no authenticated case of silicosis has been contracted<sup>1</sup>.

In many of the South Wales anthracite collieries, as also in many of the Scottish collieries<sup>2</sup>, sandstones occur just below, or just above, the coal seams; during coal-mining operations these sandstones are drilled and blasted. The Scottish coal-measures sandstones would fulfil the legal definition of "Silica Rock" in relation to claims for silicosis compensation as decisively as do those in the anthracite field. The sandstones in these two areas are alike not only in their content of quartz, but also in the size and form of the quartz grains, hence it seems clear that quartz alone is not the mineral that gives rise to highly dangerous dusts in the anthracite districts. The question arises, therefore, as to what it is that is present in the sandstones of the latter area and absent in the Scottish sandstones. It is submitted here that a petrological examination of the two series of sandstone supplies the answer to this question.

In the scores of microscope sections examined of the sandstone from the anthracite district, the dust of which has been proved to have caused many cases of silicosis, two significant facts are revealed, namely the presence in these sandstones of countless minute fibres and scales of sericite (Fig. 8) and the absence of recognisable felspar. It is clear that many of the aggregates of sericite, but not all, have been formed from the alteration of felspar (see also p. 315). In the sandstones from well-known Scottish collieries<sup>3</sup>, sericite is either absent or rare, and many crystals of unaltered felspar are present (Figs. 9 and 10). In other words, the sandstones in the anthracite field contain countless acicular fibres of sericite of the size and form they are found in the mineral residues obtained from the silicotic lungs of workmen who were employed in these collieries; the Scottish sandstones contain very few such fibres, and, indeed, compared to the myriads present in the South Wales rocks, fibres of sericite in these Scottish rocks are rare.

There is, in the author's opinion, a very interesting geological reason why the felspars in the anthracite and some other coalfields are sericitised and those of the Scottish coalfields are for the most part not converted to sericite. He will not discuss that question at present but will merely indicate that it is intimately related to the greater pressure, and hence temperature, conditions that obtained in the areas where the felspar has been completely, or almost completely sericitised.

There is one other outstanding case which will be referred to here because it has features of peculiar interest; it is that of the Broken Hill Mines, New South Wales, Australia. Many cases of silicosis have been diagnosed amongst the Broken Hill miners where "in eight years 160 mine workers were withdrawn

<sup>1</sup> The total absence of cases of silicosis in the Scottish coalfields has been kindly confirmed by the Government Mines Dept.

<sup>2</sup> A reference to the excellent coloured charts issued recently by the Geological Survey of Scotland, showing numerous vertical sections through various parts of the Scottish coalfields establishes this fact as also does the authoritative information supplied to the author.

<sup>3</sup> The names of the collieries have been purposely omitted, on advice.

as suffering from simple silicosis," and where in a similar period "of 101 men classified as suffering from silicosis plus tuberculosis there were living only 15; 86 per cent. had died<sup>1</sup>." The amount of free silica in the Broken Hill ore (and the ore bodies, be it noted, are very wide) varies from 1.62 to 17.73 per cent.; and in the "country rock" it averages under 20 per cent. free silica<sup>2</sup>. In some of the mining blocks at Broken Hill where cases of silicosis have occurred, there is no rock which could be included under any of the types of rock named in the Silicosis Schemes in English law, yet dust has been produced that, as stated, has given rise to scores of cases of this disease: that in itself is a fact full of significance. At Broken Hill, however, occurs a rock known as "sillimanite gneiss," in which the aluminium silicate mineral, sillimanite, occurs sometimes in large crystals but generally as minute fibres (Fig. 11); in fact the alternative mineralogical name of sillimanite is "fibrolite" because it so commonly occurs in fibrous form. Sericite is also abundantly present in some of the Broken Hill rocks. Here then we have rocks low in their content of free silica, but containing fibres of sericite and sillimanite, which produce dangerous dusts.

Attention was drawn to the low content of free silica in the Broken Hill ore and adjacent rocks by Dr R. R. Sayers in 1925<sup>3</sup> and by Drs Charles Badham and W. E. George of New South Wales at the International Conference in 1930<sup>4</sup>. It is of particular interest to note also that at the Conference the possibility that silicates may have played a rôle in the causation of silicosis was not entirely overlooked although it seems clear from the definition accepted at the final sittings (that the disease was caused by silica in the uncombined state) that their effect was underestimated. Dr E. L. Middleton pointed out that "silicates would, sooner or later, have to be studied systematically as the cause of pulmonary disease in industry. There is abundant evidence already that the silicates cannot be regarded as a single group showing a uniform effect on the pulmonary tissues and producing the same results of disablement and death of those affected<sup>5</sup>." Dr Badham, also at the Conference, stated that "he was by no means convinced that the silica was the whole story of their disease. He found confirmation of that view in the fact that where they had, as in Broken Hill, 85 per cent. of silicates, most of them intractable, they found in the lung after death intractable and other silicates. It was therefore reasonable to assume that silicates had a considerable effect on the production of fibrous pneumoconiosis<sup>6</sup>."

Brief reference will now be made to the clays used in the manufacture of pottery. The "clay body," consisting largely of kaolin (China-clay) formed from the decomposition of felspar, contains fibres of sericite. Fig. 12 is a

<sup>1</sup> Silicosis: *Rec. Internat. Confer.* held at Johannesburg, August 13th-27th, 1930, Dr W. E. George, p. 67.

<sup>2</sup> *Ibid.* pp. 39 and 40.

<sup>3</sup> Sayers, R. R. (1925). *Silicosis among Miners*. Bureau of Mines, Washington.

<sup>4</sup> *Rec. Internat. Confer.* pp. 39 and 40.

<sup>5</sup> *Ibid.* p. 384.

<sup>6</sup> *Ibid.* p. 62.

photomicrograph, under polarised light, of a typical "clay body" used in the English potteries; it was supplied through the courtesy of Dr C. L. Sutherland. It will be noted that fibres of sericite are numerous. These readily become freed into the atmosphere from the dried clay.

#### VII. ASBESTOSIS: THE MINERALS THAT CAUSE IT.

Although this paper is not concerned particularly with the minerals that cause asbestosis, there are one or two facts noted during the examination of the mineral residue of parts of the lung of a worker who died of this disease, that appear to be relevant here. Under the elastic term "asbestos" as used in industry<sup>1</sup> (and now in English law in the recent Compensation Scheme for Asbestosis) several kinds of minerals are included; in fact, any fibrous mineral that has an industrial application similar to true asbestos can, and often is, included under that name.

The asbestos fibres in the residue are, for the most part, several times the length of the longest fibres of sericite noted in the residues of silicotic lungs; some of the former are over 40 microns long, that is, about 20 times as long as some of the longest sericite fibres, and it is possible that with more lung material longer fibres would be found. In the series of excellent sections of this lung kindly prepared by Mr H. R. Hewer, M.Sc., D.I.C., of the Department of Zoology of the Imperial College of Science and Technology, the fibres of asbestos can be clearly seen under the petrological microscopes. The point of interest here is that the fibres in the alveoli are all minute asbestos fibres from 1 to 2 microns in length, that is about the same size as the great majority of sericite fibres found in silicotic lungs. This note may be of interest to medical authorities who have not examined such sections under the petrological microscope.

It would be unusual to find uncombined silica present in asbestos. Here then is a fibrous silicate mineral that causes a disease similar in some respects, at least, to silicosis; in other words, a fibrous silicate mineral, without the presence of quartz or any form of uncombined silica, does produce a deadly pulmonary disease.

#### VIII. SUMMARY AND CONCLUSIONS.

The results of these investigations on the mineral residues obtained from twenty-nine silicotic lungs, and of the examination of the rocks and materials which gave rise to the inhaled dusts causing these cases of silicosis, lead to the following conclusions:

(1) The bulk of the mineral residues obtained from every silicotic lung investigated by the author consists of minute fibres of the mineral, sericite, a hydrated silicate of aluminium and potassium known also as "secondary white mica." This mineral is abundantly present also in all the rocks and materials

<sup>1</sup> The mineralogical term "asbestos" is restricted to certain kinds of amphiboles which pass into fibrous varieties.

which gave rise to the inhaled dust; and it is present in these rocks and materials in minute fibres and scales of the size it is found in the residues and also in the lung tissue.

(2) Silica in the uncombined state, as quartz, is also present in these residues as relatively coarse and fine grains; it occurs, however, in amounts subordinate to sericite. Especially is this so with regard to the small number of quartz particles, as compared with the countless fibres of sericite.

(3) One relatively large grain of quartz, measuring  $10 \times 8 \times 5$  microns such as is found in the residues, is equal in volume to 800 fibres of sericite measuring  $2 \times 0.5 \times 0.5$  microns, and contributes as much silica in the chemical analysis of a residue as would 1600 fibres of sericite. This would appear to be out of all proportion to the silicotic effect of one such quartz in the bronchi and bronchioles, compared with the effect in the alveoli of hundreds of fibres of sericite.

(4) Silica in the uncombined state, as quartz, is not the chief cause of silicosis in these and certain other cases. This appears to be conclusively established, it is submitted here, by the following facts: (a) The amount of quartz and the size and form of the quartz grains in the sandstones occurring in the underground working-places in the Scottish Coalfields and in the South Wales Coalfield, are alike. The latter sandstones give rise to dust that has caused scores of cases of silicosis, whereas no authenticated case of silicosis has been produced in the Scottish Coalfields. (b) The gold-bearing quartz conglomerate of South Africa gives rise to dust that has caused thousands of cases of silicosis; the gold-bearing quartz rock of the Kolar Goldfield, India, contains more quartz than the South African rock and yet produces dust that has caused no case of that disease. (c) No quartz-bearing rocks investigated by the author are known to have given rise to silicosis-producing dust except those which also contain abundance of fibrous aggregates of sericite or of fibrous silicate minerals, loosely held together and easily freed into the atmosphere when the rock is drilled and blasted. (d) Rocks which contain a relatively small percentage of quartz (well below the minimum amount in the rock types named in the Silicosis Schemes under English law) but which do contain fibrous silicate minerals such as sericite and sillimanite, as for example at Broken Hill Mines, New South Wales, produce dust that has caused a large number of silicosis cases.

(5) These investigations are not concerned with the pathological condition produced by the minerals in the lungs. Whether they merely act as mechanical irritants causing the growth of fibrous tissue as advocated by some well-known authorities, or induce chemical changes as maintained by certain eminent pathologists, is a question entirely beyond the province of the author. His conclusions do not militate against either theory; on the contrary, they provide the former school with evidence of the presence in the lungs of thousands of acicular fibres that presumably could act as mechanical irritants, and the latter school with evidence of the presence of silicate minerals less stable than

quartz and which, because of their physical form, expose far greater surface to volume for any chemical action than do the more compact grains of quartz.

(6) Lastly, it is submitted here that it is mainly the presence in the exploited rocks and materials of fibrous minerals, be they sericite, sillimanite, tremolite, etc. (or a fibrous form of free silica as in chert or of a fibrous rock as in pumice) in aggregates which during the impact of drilling, blasting, or crushing, become freed into the atmosphere as individual fibres, that enables sufficient material in course of time to enter the lungs to cause silicosis. It is not suggested that sufficient minute particles of quartz could not, under any circumstances whatever, enter the lungs to cause silicosis, although the cases here investigated appear to show conclusively that they have not done so; but it is maintained that the fibrous minerals hasten the process so very considerably that their presence in the exploited rocks and materials is of far greater importance in causing this disease than is the presence of quartz.

#### IX. ACKNOWLEDGMENTS

These investigations would not have been commenced if Dr C. L. Sutherland, Chief Medical Officer, Medical Board for Silicosis and Asbestosis, Sheffield, had not kindly supplied the author with the first batch of four silicotic lungs and a number of microscope sections of similar lungs; they would not have been so easily continued if Prof. S. L. Cummins, Cardiff, and Dr A. F. Sladden, Swansea, had not readily supplied a large number of lungs or parts of lungs, and much valuable information concerning them; they could not have been based on so many cases if Prof. E. H. Kettle, St Bartholomew's Hospital, had not supplemented this lung material with over a dozen lungs, or parts of lungs, from his own collection, and if Dr E. L. Middleton of the Home Office had not assisted in the same direction. The extent of the help of those named is not limited, however, merely to the supply of material. They, together with Dr S. W. Fisher of the Government Mines Department, have been sources of great encouragement throughout these investigations. Prof. Kettle and Dr Middleton kindly read through the manuscript and made valuable suggestions, but it is to the inspiring discussions with them on this subject that the author is more particularly indebted. He thanks the Committee on Industrial Pulmonary Diseases, British Medical Research Council, for inviting him to co-operate with them in research on the rôle of certain minerals in the causation of pulmonary disease and the Medical Research Council for defraying the cost of the chemical analyses.

Dr H. H. Thomas, Government Petrologist, made valuable suggestions, and Mr H. R. Hewer, M.Sc., D.I.C., Zoology Department, Imperial College of Science and Technology, made a series of excellent sections of an asbestotic lung. Almost every one of his colleagues in the Geological Department has at one time or another in the course of these investigations been helpful. Mr S. Bracewell, B.Sc., D.I.C., has been mentioned in the text; Mr G. S. Sweeting, D.I.C., F.G.S., gave considerable expert help with the photomicrographs;

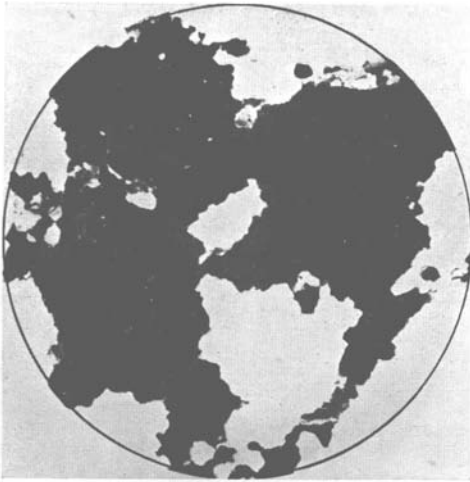


Fig. 1.

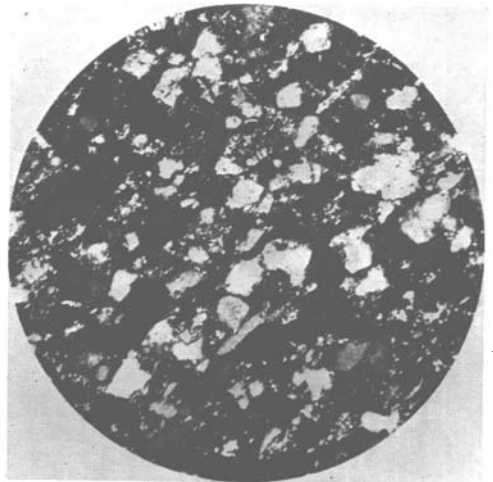


Fig. 2.

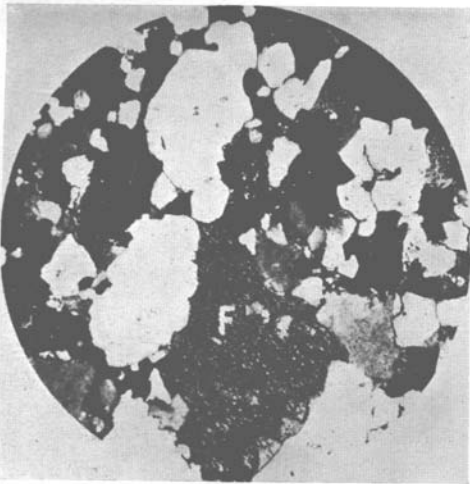


Fig. 3.

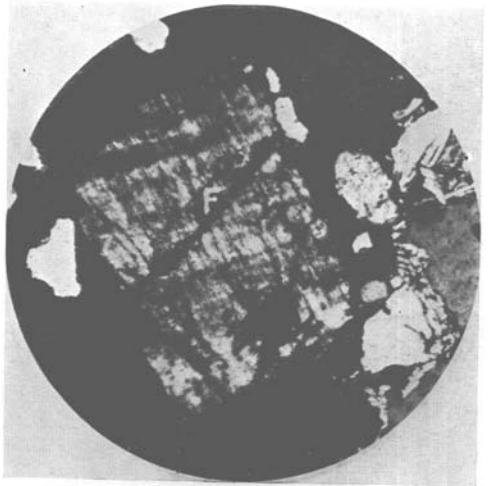


Fig. 4.

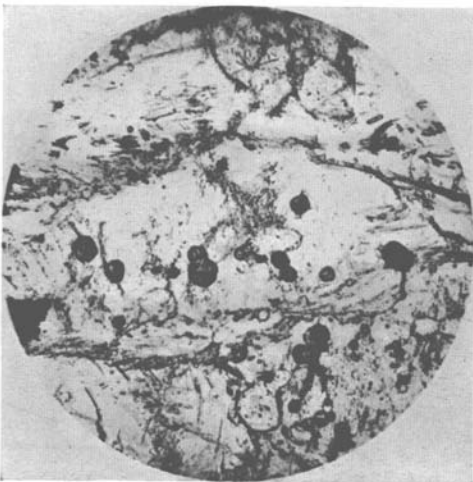


Fig. 5.

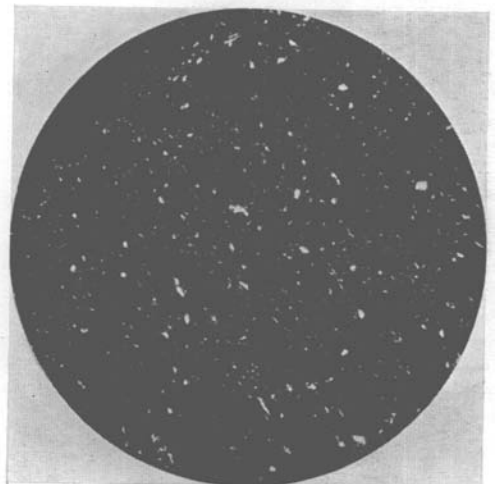


Fig. 6.

Mr E. J. Tallin, Lapidarist, exercised his skill in making the microscope slides of the mineral residues; Prof. A. Brammall kindly confirmed the determination of the minerals under the microscope; and Prof. C. G. Cullis cordially relieved the author of part of his duties and has otherwise been helpful and encouraging. Finally, Prof. P. G. H. Boswell, Head of this Geological Department, not only granted all possible facilities but has made valuable suggestions and has taken a live interest in this work from its commencement.

### EXPLANATION OF PLATE VI.

- Fig. 1. Aggregates of the mineral residue from the silicotic lung of a collier. Taken under polarised light to show that the material is doubly refracting.  $\times 30$ .
- Fig. 2. Two of the aggregates, shown in Fig. 1, of the mineral residue from the silicotic lung of a collier. Taken under polarised light to show the form of the longest fibres of sericite. The great majority of the points of light are minute fibres just out of focus.  $\times 500$ .
- Fig. 3. Finely powdered quartz taken under polarised light to show the form of the particles. The quartz, before powdering, was isolated from a sandstone in the anthracite district of South Wales which had given rise to many cases of silicosis.  $\times 70$ .
- Fig. 4. The large dark crystal occupying the centre of the field is felspar; the small fibrous aggregates inside the felspar crystal are sericite. Taken under polarised light to show a type of sericitisation of felspar.  $\times 50$ .
- Fig. 5. Microscope section of the Transvaal "Banket" taken under polarised light to show the acicular aggregates of sericite between the quartz pebbles and grains.  $\times 30$ .
- Fig. 6. Microscope section of the Transvaal "Banket" (from a different part of the reef to that in Fig. 8) to show the acicular aggregates of sericite between the quartz pebbles and grains.  $\times 30$ .
- Fig. 7. Microscope section of the Kolar (India) gold-bearing quartz, taken under polarised lights to show the absence of fibrous minerals between the interlocking grains of quartz.  $\times 30$ .
- Fig. 8. Microscope section, taken under polarised light, of a sandstone from a colliery in the anthracite district of South Wales which has given rise to dust that has caused many cases of silicosis. The clear and dark areas are quartz; numerous aggregates of sericite occur between the quartz grains.  $\times 30$ .
- Fig. 9. Microscope section, taken under polarised light, of sandstone from a Scottish coalmine. The clear and dark areas are quartz; the crystal marked "F" (white, below centre) is felspar which has not been sericitised.  $\times 50$ .
- Fig. 10. Microscope section, taken under polarised light, of sandstone from a Scottish coalmine distant from that referred to in Fig. 13. The clear and dark areas are quartz; the crystal marked "F" (near centre) is the felspar, microcline, showing complete absence of sericitisation.  $\times 50$ .
- Fig. 11. Microscope section, taken under Ordinary light, of sillimanite gneiss from Broken Hill, New South Wales. Minute fibres of sillimanite are numerous.  $\times 30$ .
- Fig. 12. Microscope section, taken under polarised light, of a clay-body used in English potteries. Fibres of sericite are numerous.  $\times 70$ .

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