PAPERS

PRESENTED TO THE CONFERENCE

HISTORICAL REVIEW OF MINING CONDITIONS ON THE WITWATERSRAND AND THE CHANGES WHICH HAVE TAKEN PLACE SINCE THE EARLY DAYS OF THE FIELDS

BY A. E. PAYNE, A.R.S.M., M.INST.M.M., GENERAL MANAGER, VAN RYN DEEP, LTD.; HANS PIROW, D.SC., D.I.C. (LOND.), M.I.M.M., GOVERNMENT MINING ENGINEER; AND FRANK G. A. ROBERTS, M. AND P.P., S.A.I.E., TECHNICAL ADVISER, TRANSVAAL CHAMBER OF MINES

A review of mining conditions on the Witwatersrand from its inception to the present day is chiefly interesting on account of the rapid change which has taken place in these conditions and on account of the successive steps for the prevention of miners' phthisis which the change in conditions has necessitated.

At no time in the history of the Witwatersrand was the eventual development of the industry fully foreseen. As new problems arose, new methods were called for, and the dust prevention campaign led to sustained effort and continuous research.

In order, therefore, to present a complete picture of the changes which have taken place in mining conditions generally on the Witwatersrand, it is necessary to describe step by step the various phases through which the industry has passed.

Mining may be said to have started on the Witwatersrand in 1886, and the first stamp mill was started in the following year.

From this time up to the outbreak of the Anglo-Boer War in October 1899 it is estimated that an approximate total of 36 million tons was crushed, or a little more than is crushed per annum to-day.

The industry progressed slowly at first, and we find that the State Mining Engineer of the South African Republic in his report for the year 1898 records that there were employed only 9,854 whites and 73,354 natives in the mining industry; whilst the Government Mining Engineer of the Union of South Africa reported in 1928 that there were in the service of the mines of the Witwatersrand for that year 21,341 whites, 176 Asiatics and 194,362 natives and other coloured persons. An analysis of the occupations of these employees would indicate that approximately 53 per cent. of the whites and 78 per cent. of the natives and other coloured persons were employed underground.

At first the workings were of course shallow, and in the oxidised or "free milling" zone, where the rock was relatively soft, friable and damp. The average depth to which this zone extended varied from place to place, but rarely exceeded 300 feet, and in some places was as little as 100 feet. From near the bottom of this zone the rock gradually became harder and more pyritic, until at vertical depths averaging in the neighbourhood of, say, 500 feet it had much the same characteristics as that which is being mined to-day.

By the year 1892 extensive deep-level companies had been formed, and drilling by machines had been introduced, principally at first for development work, and we find that the number of machine drills at work in 1896 was just over 1,000, increasing in 1899 to over 2,000 in number. These machines were of the rigged reciprocating type, and weighed up to 350 or even 400 lbs. each. They were operated mostly by miners from overseas with the assistance usually of two or three natives, but it was not until some years later that it became the practice for the natives themselves to operate the machines.

Though the "reef" had been intersected in deep boreholes, e.g. Rand Victoria Borehole in 1893, at a depth of 2,343 feet, and 1895 in the Bezuidenville Borehole at a depth of 3,127 feet, there had been very little thought for the ventilation of the mines as the depth and extent of workings increased, nor had the health of employees caused any anxiety in the minds of the managements or Government.

As long as the mines were working in the free milling zone very little dust was produced, and since the mines were shallow, and in consequence well ventilated, it is unlikely that the men came to any harm through dust.

We find that following the disturbances which gave rise to the Jameson Raid in 1895 the Government of the South African Republic appointed in April 1897 an Industrial Commission of Enquiry to look into the position of the mining industry. The records of that Enquiry can be searched in vain for any grievance as to conditions of health, or suggestion as to disability arising from the method of mining the banket.

It may be said that before the Boer War no one, or at least very few people, suspected that the mine dust was in any way injurious to health. The few who did complain were mostly surveyors who had difficulty in taking some sights on account of the bad visibility caused by the dust, and they were laughed at and told that " everyone must eat a peck of dust before he died ".

The conditions in those days, however, if compared with present standards, would appear to be very bad. Much of the drilling, especially in development ends, was done dry; blasting was permitted at any time during the shift provided it did not interfere too seriously with work, and cases of gassing were frequent. Broken rock was shovelled in a dry condition, and, generally speaking, the mines were so dusty that workmen at the end of their shift looked like millers. The shifts were materially longer than at present, the average being in the neighbourhood of ten hours. Night shift for ordinary work was common practice and the interval between shifts was very short; indeed, on development work there was no interval at all in some cases, the common practice being for the miner to drill over the round, turn on the compressed air and blast the cut, returning in about half an hour to blast the round, having in the meantime sent word to his mate on the surface that it was time for him to come down. These men thus worked no regular shift, but relieved each other whenever they happened to finish a round.

The conditions under which they lived would also be described as bad in comparison with those of the present day. There were but few change-houses, and where these were provided the tendency was for the men to refuse to use them. Most of the men lived in single quarters provided by the mining companies, two, and sometimes three, in a room which, while perhaps adequate in size, would be said to-day to be insufficiently ventilated. In the earlier days these rooms were made of wood and iron, and the variations in temperature were considerable. As time went on, however, it became customary to line such rooms, first with matchboarding and afterwards with sun-dried brick and plaster.

In regard to social amenities, places of amusement, recreation facilities, etc., it could be said that these were non-existent, meagre, or confined to the towns, with the result that many of the men, and especially the single ones, tended to congregate in bars and to indulge in month-end orgies.

On the medical side, the conditions on the Witwatersrand have never been very bad, except perhaps in the earlier days and during outbreaks of what was commonly called in those days " camp fever ". Men were quick to realise the advantages of sick benefit societies, and these were brought into being at a comparatively early date, and it can be said that, generally speaking, they were functioning with some success, especially on the larger mines, as far back as 1895-1896.

It is not until the Government Mining Engineer of the Transvaal Mines Department, in his report up to June 1902, introduces the subject of the health of workmen that any appreciation seems to have been given to the matter. In his report first mention is made of " miners' phthisis " as a disease " which seems to be peculiar to men employed in rock drill work ". It must be understood that up to this time the breaking of ground in stopes was almost entirely done by hand labour, i.e. by native labourers drilling single handed. Machine drilling was confined to development work. Careful enquiry at this time elicited the fact that out of the 1,177 rock drill men employed on the Rand prior to the Anglo-Boer War, 225 or 16.75 per cent. were known to have died from miners' phthisis. The actual number may have been greater. It is certain, however, that if it had not been for the break in the working of the industry due to that war the mortality rate would not have been so fully realised. In considering this rate, however, it must be borne in mind that most, if not all, of the men concerned had worked previously in overseas mines in Cornwall, Australia, and elsewhere, and may have laid the foundation for their disease in these mines.

In 1902 the Governor of the Transvaal appointed a Commission to enquire into and report upon the prevalence and causes of the disease known as " miners' phthisis " and to make recommendations as to the preventive and curative measures which should be adopted. One outstanding result of their enquiry, which was made known in 1903, was that:

> Although the incidence of the disease appears to be more marked in miners who have been working rock drills for some years, yet it is also found to prevail amongst miners who have never worked them;

and the Commission recommended, amongst other things, that:

(1) The discharge of minute angular particles of dust in the mine air should be prevented;

(2) The working places should be supplied with air in sufficient quantities to render harmless and sweep away all vitiated atmosphere.

The fact that other than rock drill miners were affected by this disease gave a spurt to improvements in the ventilation of workings and in the use of respirators for those actively engaged in rock breaking.

Early development work was done by hand drilling, and headings were consequently on the small side. Practically all the early shafts were inclines with three relatively small compartments; and the drives were about 6 feet by 4 feet. When rock drills were introduced these dimensions were increased somewhat, but as a general rule the headings still remained small, namely, about 6 feet 3 inches by 5 feet 6 inches.

It can be said that most of the mines turned out to be poorer in depth than was expected, and this, together with heavy capital expenditure and other causes, necessitated increases in capacity materially beyond what the mines were originally laid out to produce, and brought about a congestion in the matter of handling rock, men and material.

In the year 1903 it was realised that, owing to the increasing average depth of the mine workings, it was no longer possible to allow the European miners to come up for their midday meal, and the fact that these men must in consequence remain in the mine for the whole duration of their shift was an additional urge towards the improvement in the distribution of the ventilating current, hitherto only due to the difference in pressure of the atmospheric conditions. Steps were taken to improve this pressure by various means, such for example as building up one or more of the compartments of the up-cast shaft; erecting drill sharpeners' furnaces at the bottom of the up-cast, and to a small extent in carrying light pipes from the face of drives to an up-cast shaft or raise.

Arising from the congestion referred to above, it was common practice for persons, and especially natives, to walk up long distances to get out of the mines. This position was gradually improved by the sinking of new shafts and the installation of larger and more powerful hoists, and in 1917 the Mining Regulations laid it down that the manager should provide arrangements for hoisting all persons when the height exceeds 500 feet measured vertically. (See Regulation 158 (25).)

In addition to the purity of the air, and freedom from gases due to the quantity of explosives used, attention was now first paid to the quality of the lubricating oils used in compressing air for the machines, through the exhaust from which it had been proved that in some cases dangerous gases had been disseminated into the mine atmosphere. At the same time attention was called to the use of damp and weak detonators, as well as to both the overcharging and the undercharging of holes with nitro-glycerine explosives which result in the production of noxious fumes. In this same year (1903) the Chamber of Mines, a body formed in 1889 to represent the joint activities of the mining industry, offered prizes for the best method of allaying dust caused by machine drilling. The first prize was won for a water-spray or atomiser, and the second for a patented water-fed drill.

About this time improvements in machine drills designed to increase the speed of drilling began to make their appearance. The heavy old-fashioned type of reciprocating machines were gradually replaced by lighter and faster drilling ones, and a few machines of the Leyner hammer-drill type were introduced. These last-mentioned machines, however, employed hollow drill steel through which compressed air was blown in order to keep the drill bit free from chips, and they were thus, as dust producers, much worse than any of the machines which had hitherto been used. Indeed, they produced so much dust that it was usually impossible in development ends clearly to discern the operators. Dry air blowing machines of this type, however, did not remain in vogue for more than a few years.

It is at this stage that the industry was first confronted with the extreme conservatism of the operatives in the use of any dust-preventing devices. They objected to sprays designed to prevent the escape of dust formed in drilling and operated from the exhaust of the machine, on the ground that it made them too cold. They objected to sprays and the use of water generally, on the ground that it gave them rheumatism, and so on, and that they would just as soon die of miners' phthisis as of those other diseases which wet working places might cause; and they objected generally to any of the precautions which by occupying time tended to decrease their earnings. The Government, and indeed the industry itself, were forced therefore to recognise that outside the improvements in devices for dust allaying there would appear to be need for special legislation to enforce the use of any recognised means for the prevention of silicosis.

Act No. 54 of 1903, and the Mines and Works Regulations promulgated thereunder, is the first step of a long series of legislative measures to control the conduct of mines in the direction of the use of the best form of preventive measures, which continuous research in the cause and prevention of miners' phthisis showed to be desirable.

Starting with Chapter VI of the 1903 Regulations, containing four regulations on ventilation, and one reference, Chapter IX, Regulation 97 (8), that the ganger shall be responsible that no person enters the working place " until the fumes caused by the explosives shall have been sufficiently dissipated ", we have to-day Regulations in great number designed to control the ventilation; chemical analysis of air; limitation of blasting operations; exposure of persons to dust and fumes after blasting; the replacement of vitiated air by a certain volume of fresh air after blasting; the conditions for working in back stopes; the entry into working places; the use of water under adequate pressure in all working places; the use of water when tipping and handling broken ore; the use of water in drilling any hole; the clearing or blowing out of any hole after drilling; the use of tamping material in charging, and the quality of the lighting torch; the interval between blasting shift and return to work in the mine; the control of water blasts and auxiliary ventilation in development ends after blasting; etc. To ensure the proper observance of these precautions, responsibility is laid upon miners and officials of all grades from manager downwards. In a Code of Regulations, which twenty-five years ago could be comprised in a volume of 52 pages, we find now detailed Regulations for the health and safety of the mines comprising a volume of over 200 pages, of the same size, under Act No. 12 of 1911 and many subsequent revisions of the same under Government Notices.

It will be interesting to return to the history of the investigation into the disease of miners' phthisis, now bearing in mind that every relevant factor in prevention has in one way or another found its corollary in legislative injunction.

In 1907 the Government of the Transvaal appointed a Commission known as the " Mining Regulations Commission " to report on the working of the Mines, Works and Machinery Regulations, with special reference to (amongst other things) ventilation and the better protection of the health and safety of persons working in mines.

This Commission extended its enquiry over the years 1907-1910, and laid the foundation for the scientific investigation into the disease of miners' phthisis. We gathered that all true cases of miners' phthisis are primarily cases of silicosis, and that finally a tuberculous infection commonly becomes superimposed upon this condition and the symptoms and course of the disease alter accordingly. The suggestion arose also as to whether the exposure to noxious fumes might be a predisposing cause of miners' phthisis, and we were told that medical opinion was against exposure to such fumes and that preventive measures should follow the lines of:

(1) The prevention of dust inhalation;
(2) The prevention or removal of noxious fumes resulting from explosives;
(3) The prevention of silicosis.

By amendments to the 1903 Regulations the responsibility of the manager had already been extended to the compulsory use of water with machine drills, and to the prohibition of the removal of dry and dusty rock unless it had been wetted so as to prevent the escape of dust into the air. It was now for the first time recommended that responsibility should be placed on the manager for supplying the necessary water and on the miner for its use; and that inspectors of the Mines Department were to be instructed to pay special attention to its use (24 December 1908). On the adoption of these recommendations, the supply of water had to be made continuous, and all places where development work was carried out and every dry and dusty stope (when the natural strata are not wet) had to be kept damp. Blasting had to be so arranged that men working in other places were exposed as little as practicable to dust and smoke. The use of water by the miner was tightened up, and in drilling holes with any percussion machines he was enjoined to use a water jet or spray, and he was not allowed to enter a working place after blasting until the fumes had been sufficiently dissipated, unless he was wearing an effective respirator or other apparatus to prevent the inhaling of fumes or dust.

The next step was to enact that the miner should keep the floor and sides of his working place within a distance of 10 feet sufficiently damp to prevent dust being raised by the exhaust from his machine. Further, that rock to be shovelled should not only be superficially damp but should be kept damp in the process of shovelling. To ensure that these precautions were being carried out, and to combat the seeming indifference of rock drillers, it was laid down that a shift boss should report to the manager daily whether the requirements of these Regulations were being observed or not.

At about this same period (1908) attention was directed to contrivances for the catching of dust caused by the drilling of holes. Some of these had been used in Western Australia and in Cornwall, as substitutes for water jets and sprays which in the drilling of steeply inclined holes caused discomfort to the workmen, added humidity to the atmosphere, and were thought to tend towards the production of ankylostomiasis and other diseases. These devices took the form of flexible collars fitting tightly against the rock, and through which the drill steel operated. In some cases the dust was caught in a bag, and in other cases it was sucked away by an air jet ejector and led into some form of dust trap. None of these devices, however, were successfully adopted.

In most mines in those days, and especially in those mines where the capacity of the reduction plant had been increased, there was an inadequate number of working places from which to obtain the necessary amount of ore. This shortage of working faces necessitated a heavy development programme, and a double shift method of working with blasting at least twice every twenty-four hours.

At about this same time and with a view to reducing the danger arising from the dust and fume caused by blasting, experiments were made with various methods of projecting into the air at the time of blasting in development ends a volume of finely divided water, and these experiments led ultimately to the general adoption of an apparatus known as a water-blast, which has now by regulation to be used at blasting time in all development ends and again before persons are permitted to re-enter.

When, as a result of the increased amount of development work, the number of working places became adequate, the custom of miners returning to their working places too soon after the blast was abandoned and single shift blasting introduced.

The consideration given to the incidence of tuberculosis by the Commission of 1907-1910 revealed the prevalence of this disease in particular amongst the native workers, and gave rise to the promulgation of preventive measures already known to be effective in combating this disease elsewhere than in mining. It initiated the examination of natives prior to engagement for mine work, and contemplated the possibility of having to take similar steps in the case of white workers. In both cases it was urged that infected workers should be excluded from the mines as soon as the disease had been diagnosed.

The sanitary arrangements underground were very bad in the early days. Indeed, it could be said that they were bad up to less than twenty years ago. At first no sanitary conveniences of any description were provided, and persons wishing to relieve themselves had no option but to walk out of the mine or to go into some disused workings. Afterwards it became customary for persons to use the rock boxes, so that the faeces would be hoisted with the ore. Later on, after the necessary provision of an adequate number of latrines had been made, it was very difficult to break the natives of their bad habits and to educate them to use the latrines.

It was not until well after the Boer War that the mines began to provide drinking water underground. Prior to this the men made their own arrangements and either took water down with them or drank from one or other of the numerous water-bearing fissures.

Attention was now first drawn to the need for cleansing shaft stations and such waiting places as workmen were in the habit of using in the mines, whilst the housing conditions of both black and white were thoroughly reviewed. Change-houses for the white miners were made compulsory. Medical inspectors for the mines were recommended, and in the Johannesburg District this duty was taken over by the Medical Officer of Health of that town, and has been carried out very thoroughly ever since.

Another important consideration of the Commission was the duration of the working hours of mine employees. The chief ground for the reduction of working hours claimed by employees was that of health. The Commission found that there was no reason why work underground should be more unhealthy than work on the surface. In practice, however, this was found difficult to ensure. On the other hand, it was found that miners were not being employed more than eight hours a day at their work, the rest of the time being occupied in taking their meals, in getting to and from their working places, and in other ways. Recommendations were, however, drafted and later brought into force in Act No. 12 of 1911, limiting the hours of work to forty-eight hours per week, and the hours of certain employees to not more than ten per diem. The erection of underground drill sharpening shops was prohibited except under conditions controlled by the Mines Department.

This Commission, in investigating the quantity standard of air to be supplied in accordance with the 1903 Regulations, found that without detailed Regulations it was difficult to enforce. It turned its attention also to the quality of the air. It laid down a legal maximum for certain noxious gases, e.g. CO_2, CO, and nitrous oxides. It pointed out that suitable mechanical appliances should be erected and operated to direct the ventilating currents when natural ventilation failed to operate; that old workings should be closed off, and plans should be kept to show the necessary stoppings and methods of control. In development work where machines were operated suitable arrangements were to be furnished for removing the dust, smoke and gases after a blast, and no man should return until the air was clear of such.

Undoubtedly a great deal of valuable ground was covered by this Commission, and the book of Regulations which, as above referred to, had been contained in 52 pages, was extended to 136 pages of the same size. The responsibility of the mine managers was extended to include the supply of clean water and suitable waiting places for native workmen and causing them to wait there, and powers were given them to take such disciplinary steps to enforce the requirements of the Regulations as the Inspector of Mines might direct or approve.

During the period covered by the 1907 Commission the mining industry had passed from the control of the responsible Government of the Transvaal to that of the Union Government of South Africa. A greater change was, however, taking place in the personnel of the operatives. In the early days of the industry the skilled white miner was almost entirely recruited from overseas, either from Europe, and principally from England, or from Australia. Owing to the incidence of the disease of miners' phthisis amongst these men, and to other causes, the mining field was ceasing to be attractive, and during the industrial trouble which arose in the industry in 1907 a large number of South African nationals were for the first time engaged by the mines and drafted into the occupation of mining, very largely as supervisors of the native gangs, and primarily, of course, in the less skilled operations of tramming, shovelling and other underground work. The South African national naturally lacked the mining knowledge of the overseas miner who had been brought up to mining since his childhood, and hence at first a great deal of care and training was necessary. In the course of time, however, the South African national began to get educated in this work, and at present over 60 per cent. of the employees of the mines are South African born, whilst a much larger percentage of those working underground are of that class.

The Union Government in February 1912 appointed a Miners' Phthisis Prevention Committee "to enquire into, by experimental and other investigation, and to report from time to time upon the improvement of, the methods for the prevention of miners' phthisis in the Witwatersrand gold mines, and to advise upon the introduction of a systematic and uniform policy and the amendments to the Mining Regulations which may be necessary for combating the disease". This Committee reported in March 1916 on its work up to the end of 1915, and finally in January 1919 on its conclusions. There were throughout this period preliminary and special reports, as well as many memoranda submitted to the Government. Parallel with the growth of knowledge came legislative steps to enforce prevention, all the more necessary because of the change in the personnel of the miners and of the ignorance of the subject amongst them, now allied to the natural conservatism of the individual.

The material knowledge of the disease gained by this Committee was very great, but it may be said that in its conclusions it endorsed the already known fact that avoidance of the inhalation of air charged with injurious dust was the most important line of action towards the elimination of the disease amongst the operatives. With this fact in view, it was recommended that single shift blasting should be introduced; and the legal and moral responsibility of all mine employees was stressed as to the proper use of water for dust allaying purposes.

The Committee gained accurate knowledge of the incidence of the disease by medical examination ot miners and a careful analysis of the silicotic condition of such men. Examination of the lungs of deceased miners gave rise to a knowledge of the size of the dangerous dust particles, and this led to the introduction of apparatus for the measurement of dust in the mine atmosphere.

At the same time it was first mooted that a careful selection of the recruits amongst the white miners would be an important preventive measure. It was also first suggested that main travelling shafts should be downcast and men should be kept out of upcast shafts after blasting " until the air is free from dust and fumes ". The Regulations drafted to carry out the preliminary recommendations of this Committee were coded in an issue of the Mining Regulations of 1913. Briefly, the use of water for dust allaying purposes was extended and its use detailed. For example, the area round a working place to 25 feet instead of 10 feet had now to be kept wet. No one should enter, or permit anyone to enter, a close place after blasting within thirty minutes, and then only if the air was free from dust, smoke and fumes perceptible by sight, smell or other senses. The manager was called upon to arrange the time for blasting operations so that workmen should be exposed " as little as practicable " to the fumes and dust from blasting. The manager should supply a constant supply of " clean and odourless " water in pipes of not less than a certain size and not less than a certain pressure, such pipes to be carried to not less than a certain distance from the face. Water blasts were to be installed in every development end. No person should be allowed to remain in the mine if the air contained dust, smoke or fumes perceptible by sight, smell or other senses. The cross ventilation of miners' back-to-back quarters was provided for. Miners must acquaint their native workmen of the requirements of the dust-preventing Regulations. The manager shall keep all main travelling ways wet as far as practicable; shall cut off from the ventilating currents old stopes; shall place ring sprays in downcast shafts not naturally wet. After 1 January 1915 no one shall be permitted to blast the cut and round separately in the same shift in the same development end. Finally, provision should be made for recording the measurement of dust in the mine air as periodically determined. The use of a water jet with a percussion machine should be coupled with " or the use of a drill with axial water feed ". The collaring of holes with machines should have a special volume of water used in the process of collaring. The tube used for drilling holes should be inserted in the hole so that the water might be brought to the cutting edge of the drill. After a certain date only an axial water feed machine should be used for raising. The Inspector of Mines should fix an interval of time for each mine between the time of blasting and the next on-coming shift of workmen. An official should be appointed to each mine to report upon the water service, ventilation and prevention of dust.

It is useful to record the improvement over this long period of the conditions in the mines in the direction of dust prevention as reflected in the opinion of Mr. J. E. Vaughan, who had been away from the Rand as Inspector of Mines in Natal for some years and returned to note the marked improvement, and reported to the Government Mining Engineer under date May 1918 (*vide* Appendix No. 8, page 97, *Final Report of the Miners' Phthisis Prevention Committee*, Johannesburg, 10 January 1919). Improvement was noticeable in the attitude of the operatives to the many increased Regulations and the observance of them. There were improvements also in the water supply, dust sampling, and general cleanliness of the mines and working places. Water was everywhere being used; the air of the mines was free from visible dust; no dust was noticeable in the nostrils of the operatives. Improvements could still be made in the direction of the ventilating currents.

During this period there had been a further revision of the Mining Regulations. In 1913 the book was enlarged from 136 pages to 177, and in 1917 by a further addition up to 194 pages. There were of course additions for safety purposes other than those for the prevention of miners' phthisis.

The principal alteration in connection with Chapter VI on ventilation was that the amount of fresh air to be supplied for every person employed underground should be not less than 30 cubic feet of air per minute during the full period of twenty-four hours. The current should be suitably split and each ventilating district should receive its standard. Determinations of the quantity actually circulating should periodically be made. The replacement of air after blasting in dead ends was regulated and no working in back stopes was allowed without conditions imposed by the Mines Department. Provision was made for the duties of the ganger (Chapter IX) to wash over the face and immediate vicinity with water under adequate pressure before work was commenced. He was not allowed to use a percussion machine other than an axial water-fed machine without an additional water hose, nor a hand drill without a wet swab. Nor could he blow out a hole with compressed air unless he had first applied sufficient water to prevent the formation of dust. No person should allow water to run to waste. He shall report any cases of gassing, however slight.

It must not be supposed that all this time progress in the combating of the disease of miners' phthisis was confined only to such bodies of men as were working on the Government Miners' Phthisis Prevention Committee. The Chamber of Mines in 1914 appointed a Standing Committee on Dust Sampling. This Committee undertook the standardisation of methods for the determination of dust in the mines. It carried out periodic dust surveys of all the mines and created a laboratory for accurately determining the samples. At the same time it embarked upon a considerable field of research work, as well as being available for testing any dust preventive devices submitted to it or to the industry. Some of this work is carried on to-day by this Committee, and some has devolved upon the dust inspectors appointed on each mine according to the Mining Regulations. A ventilation expert attached to the Committee lectures to these mine dust inspectors, and the standard of knowledge is improving.

When water was first used for dust prevention and allaying, little or no effort was made to ensure its suitability for that purpose, and the nearest water available was used irrespective of whether it was clean or otherwise. As time went on it came to be recognised that dirty water when atomised might actually put dust into the mine air rather than allay it. The practice for some years past has been to use only clean water free as far as possible from fine silica particles, and approved by the Committee.

Through the chemical analysis of mine waters; of different kinds of mine rock; through the analysis of the dust produced by different kinds of machines; the analysis of air samples and the constant improvement of sampling methods, whether by sugar tube or konimetry, this Committee has a fine record of close and conscientious observance of the dust conditions of the mines. It is dealing to-day with dust particles both in quantity and magnitude of such small dimensions that the dust in the atmosphere of the mine can be compared to a possibly noxious gas which must be swept away and replaced by fresh air, rather than that any further means of allaying it could be attempted with success.

The Chamber of Mines also in December 1915 introduced on its own initiative a scheme for annual holiday leave, where under all mine employees, subject of course to certain conditions, receive an annual holiday on full pay (not exceeding 22s. per day). Under this scheme underground employees receive fourteen consecutive days' leave (of which the twelve weekdays are on pay) after one year of continuous employment; twenty-one days' leave after two years of such employment, and twenty-eight days' leave after three years, and there can be no doubt that this welcome break is of considerable value in preserving the health of mine employees.

The managers of the mines, several of whom had contracted the initial form of the disease of miners' phthisis, i.e. silicosis, were as a body very active in their insistence upon the best-known methods of dust prevention being strictly enforced. The method of single blasting has already been referred to, and was undoubtedly a most important factor introduced on the initiative of the managers themselves. Another important innovation was their recommendation in July 1915 (*vide Time and Labour Saving*, Association of Mine Managers, 1916) that a Central Bureau for the systematic examination of the physical fitness of men engaged in underground work should be established. This suggestion was adopted in 1916 by the Union Government, who in 1912 had framed legislation for the compensation of persons suffering from miners' phthisis. The trend of the Union Government's legislation in the matter of compensation for miners' phthisis does not come within the scope of this historical review of mining conditions on the Witwatersrand, and is therefore being dealt with under another heading. It must, however, be remarked that there is but little doubt that, following the increases in the amount of compensation awarded under the

Miners' Phthisis Acts, a number of persons, not realising the seriousness of silicosis and its tendency to progress into miners' phthisis, carelessly or deliberately and to the danger of others exposed themselves to dust and fume with a view to obtaining compensation. This particular phase lasted for some time, but it is not suggested that anything of the kind has been done in more recent years.

Following the efforts of the Miners' Phthisis Prevention Committee (1912-1918) previously referred to, the Mines Department instituted a systematic survey of the mines to ascertain in what way the provisions of the Regulations were being observed. This was found to be helpful to individual managers, and attention was particularly directed to ventilation, water blasts, night shift work, machine drills, shaft sinking and organisation, which still left room for improvement. In the matter of machine drills the Leyner type and axial water feed machines were rapidly replacing the reciprocating type of machine, and it was noticed that whilst the speed of drilling operations was increased by the application of water through the hollow-drill steel to the cutting edge, large quantities of dust were created by these machines through the passage of air down the hollow steel and the blowing up of small bubbles of air containing dust through the sludge discharged in drilling. These bubbles burst and, though containing exceedingly fine particles of dust, created a dangerous atmosphere for the operatives. It was found that, even in shaft sinking, where the shaft bottom was covered with water, the atmosphere at the shaft bottom contained dangerous quantities of dust when this type of machine was in use.

A long investigation commenced into the use of the Leyner type of machine and into the nature of the dust produced by it. It was found that by the use of a long piston the excess air could be prevented from passing down the drill to the cutting edge, and legislation was introduced to prohibit the use of any other than this type of machine, at first only in development work, and subsequently in all kinds of work, unless the machine was fitted with a front head release ring for the escape of air.

It followed from this investigation that the Government Mining Engineer should have power to prevent the introduction of any type of machine which might be dangerous to the operatives in its dust-creating properties, and also that for similar reasons he should have power to prohibit after due notice any type of machine already in use. Such powers were accordingly taken by the Government Mining Engineer under the Mining Regulations in 1922.

At this stage it will be of interest to point out that the heavy reciprocating drills of the early days drilled holes averaging from 6 to 7 feet in length with a diameter of about $2\frac{1}{2}$ inches at the collar and about $1^3/_8$ inches at the bottom. These machines in stoping rarely drilled more than four or five such holes during a shift.

The present-day hand-held jackhammers drill holes averaging from 3 to 4 feet in depth with a commencing diameter of about $1^1/_4$ inches and a bottom diameter of about 1 inch, and it is a common thing for these machines to drill as much as 120 feet in a shift; the average for the whole Rand being in the neighbourhood of 75 feet per machine shift.

Another point which may have some bearing on miners' phthisis is that prior to the outbreak of the Great War in 1914 the mines used blasting gelatine almost exclusively for development work, and 60 per cent. gelignite for stoping, the average strength of the explosives used being in the neighbourhood of the equivalent of 81 per cent. nitro-glycerine, whereas to-day the average strength used is in the neighbourhood of 55 per cent. nitro-glycerine. Another way of illustrating this change would be to say that prior to 1915, 0.83 lb. nitro-glycerine was used to break a ton, whereas the average consumed now is in the neighbourhood of 0.58 lb. nitro-glycerine per ton broken.

The so-called " contract " system has been a feature of mining on the Witwatersrand since the early days of the fields. It has been alleged that this system, which is in reality a method for paying European miners at piece-work rates, was to some extent responsible for the causation of miners' phthisis, in that men were induced under it to neglect precautions for the prevention of dust for the sake of additional gain. This matter of underground contracts was enquired into by a Government Departmental Committee in 1917, and this Committee found that the " contract system is not necessarily deleterious as regards the health or safety of those concerned, or morally unsound and against the public interest ". (Conclusion No. 2.) (See paragraphs 32 and 33 of the report of the Committee.)

A further Miners' Phthisis Commission was appointed in 1920, primarily to deal with legislation for compensation. It went also fairly thoroughly into the preventive measures in use at the time. We find in this Commission's interim report the first reference to the suggestion that " the use of water for dust allaying is nearing the limit of its effectiveness and that therefore additional methods, amongst which ventilation ranks foremost, will have to be relied upon for further progress in this direction ". This knowledge was given to the Commission by the work of a Joint Committee of members of the Mines Department and the Chamber of Mines Dust Sampling Committee, who in particular investigated the efficiency of water blasts in development ends and the amount of air required after the blast to clear the end of dangerous dust particles (Reports 13/10/1922). This arrangement for attacking problems in ventilation was found to be useful, and was extended during the year 1923 to testing the best method of ventilating a close end when work was being carried on, especially drilling by machines. The quality of the intake air was thoroughly investigated and much knowledge obtained as to the direction in which improvements in the health conditions of the operatives could be made.

In improving the Leyner type of machine and reducing its dust-producing properties when air was allowed to pass down the hollow-drill steel, it was noted that the size of hole in the drill steel and the pressure of water were important factors in dust control. Whilst the long piston type was compulsory for use in close ends, the Government Mining Engineer intimated to the industry in April 1925 that he thought the time had arrived for prohibiting all machine drills passing air down the hollow jumper and that only machine drills approved by him should be permissible in all classes of work. He agreed to tests being made as to the relative importance of the many variables in the matter, but hinted that the adoption of a front head release to all machines immediately would appear to be justified, and arrangements to carry out this were made law as from 23 October 1926.

The tests conducted extended over a period of about two years, and were made in a test chamber at the Consolidated Main Reef mine, under the control of an Investigating Committee composed of members of the Central Mining and Investment Corporation's engineering staff and the Chamber of Mines Dust Sampling Committee. A report issued in July 1927 demonstrated that with release ports, maximum bore water tube and an extra hose for collaring, the dust produced by rock drills would be reduced to such a small amount as to render it a very minor factor in the production of silicosis.

This conclusion is of importance when it is considered that from 1923 onwards the number of jackhammer machines introduced into the mines increased, until to-day in many mines all ground is broken by machine drills of this type. The care of the water tube is an important factor and has been very largely brought under control by the increase in length of the front head bushing and shank of the machine drill by which, primarily, better alignment of the drill steel is obtained.

Under the provisions of the Miners' Phthisis Acts Consolidation Act, No. 35 of 1925, a permanent Committee was appointed to watch the methods of preventing miners' phthisis already in force and to investigate any new ideas. Representation on the Committee is given to all bodies of workers, and it is hoped that the improvements in the future may come from such a body. For the present the Committee is chiefly concerned in the standardisation of methods of measurement of the dust contents of the air by the method of konimetry. It has also conducted certain investigation into the quantity of dust present in the intake air of the mines and the increase in dust contents of this air in its passage through the mine.

Difficulties in the maintenance of proper water tubes in machines have caused the Government Mining Engineer to give notice to the industry in June 1928 that the development of external water feed devices should be advanced as rapidly as possible and that the use of internal water tubes would be prohibited after some future and possibly early date.

The most recent difficulty is to combat the incidence of tuberculosis, and a Tuberculosis Research Committee is now sitting. It has promulgated the opinion that "the excessive use of water underground may do more harm than good in the efforts towards the prevention of this disease, and that it certainly is liable to produce deleterious effects on health in other directions, especially in the production of tuberculosis, a disease intimately associated with silicosis".

To sum up, it may be said that the steps taken to combat miners' phthisis on the Witwatersrand have been as follows:

1. The prohibition of promiscuous blasting during the shift.
2. The prohibition of blasting the cut and round separately on the same shift in the same development end.
3. The limitation of blasting (except in a few special circumstances) to one period only in each day, and the provision of a period of several hours (from three to seven depending on circumstances) after each blast during which persons are not allowed in working places, and the dust and fumes caused by blasting can be swept away.
4. The provision of waiting places which can be kept free from dust and fumes, so that at the end of the shift all workers can be hoisted without coming into contact with such dust and fumes.

5. The provision of improved water feed drills designed to prevent the formation of dust in drilling.
6. Improved ventilation and better distribution of the air available so as to first dilute and then remove the vitiated atmosphere.
7. The use of water in all cases for the prevention of the formation of dust, and for the allaying of such dust as may be formed in the various operations.

There is also another feature which must have had a most important effect on the mines of the Witwatersrand, namely, the establishment of the Miners' Phthisis Medical Bureau for the initial examination of all persons who wish to commence mining, and for the periodical examination of those who are engaged in that pursuit. This matter, however, falls under another heading and will not be dealt with in this historical review.

In regard to 7 above, namely, the use of water, it may be said that one of the outstanding features of the preventive measures which have been adopted on the Witwatersrand is the extent to which the use of water has been carried. Only a comparatively short time ago the mines were most prodigal in the use of water, which, without being exactly wasted, was "slopped about" everywhere, and no effort made to prevent the mine air becoming saturated, or nearly so, with water. Recently, however, and especially in the hotter and deeper mines, it has been borne in upon those responsible for their management that water in excess of that which served a useful purpose was being used, and that some of the ventilation and other problems connected with deep level mining were thereby being accentuated, and efforts were commenced to reduce excessive and unnecessary use of water. Great care will be necessary in introducing any changes; for having educated all operatives in the use of water; having provided the water at suitable pressure in every working place; and having encouraged its use by many contrivances, it will not be an easy problem to limit its use without endangering the effectiveness of the present organisation. The operatives do, however, require relief from the lack of cooling power in the ventilation currents of air in mines working at great depths. Any reduction in the saturation of the air will be beneficial in this direction. New legislation is being considered to impose a katathermometer standard on the management, and methods of mining are already being adopted which will facilitate the sweep of air up the working place, and if such a practice can be made general it is possible that the excessive use of water can be limited without re-creating the dust evil. A review of the history of the incidence of miners' phthisis cannot close with a claim that it has been overcome. That the dangers are much lessened is readily acknowledged, but much yet remains to be added to the sum of human knowledge, and perhaps not least is the desire to find immunity from this disease for the operatives, white and black, of the Witwatersrand mines.

This historical review in the changes which have taken place in the mining conditions on the Witwatersrand would not be complete without some further reference to the changes which have taken place in the methods of working *vis-à-vis* their possible bearing on the matter of miners' phthisis. The more important of these changes may be summarised as follows:

1. The introduction of heavy rigged reciprocating machines operated by Europeans to replace native hand drillers in the wider and harder stopes.
2. The change-over to similar machines of a lighter type operated by natives under the close supervision of Europeans.
3. The change-over to machines of the hammer drill or Leyner type, including the change-over to air-fed hand-rotated hammer drills. Some of these machines used air only through the drill steel; others air and water, and some, especially the last mentioned, solid steel.
4. The elimination of machines which used air only through the drill steel and the substitution of machines using air and water or water only, with the simultaneous introduction of hand-held hammer drills.
5. The elimination of all forms of reciprocating drills and drills using solid steel, and the more general adoption of hand-held drills of the jackhammer type.
6. The introduction and general adoption of the cradle as well as hand-held machines designed to minimise the amount of air passing down the drill steel and to use as far as practicable water only.

Simultaneously with the changes enumerated above there has been a change over from hand drilling to machine drilling. This change is illustrated in the following tabulation:

Period: six months ending	Fathoms broken in straight stoping:	
	by hand	by machines
31 December 1914	52 per cent.	48 per cent.
31 December 1924	22 ,, ,,	78 ,, ,,
31 December 1926	12 ,, ,,	88 ,, ,,
31 December 1928	7 ,, ,,	93 ,, ,,

There have, of course, been a large number of other important changes of far-reaching effect, other than the ones referred to herein, but with the exception of the fact that the mines have become more extensive, deeper and consequently hotter, these other changes can have but little, if any, bearing on the miners' phthisis position.

Conclusion

The dust and ventilation problems on the Witwatersrand to-day can be said to be totally different from those prevailing at the beginning of this century. The systematic efforts which have been made since 1911 have resulted in the disappearance, for all practical purposes, of visible dust underground. Similarly, it can be claimed that, owing to improved organisation and mechanical ventilation, exposure to fumes or gases rarely occurs on these fields. Yet the main problem is far from being solved. The greatest obstacle to improvements at the present day lies in the fact that the workings are so far flung and so extensive as to make the cost of adequate ventilation for sweeping out the remaining invisible dust prohibitive on most mines.

The natural limitations consisting of the great depth of workings, narrow reef and large blocks of unpayable ground (particularly on the Far East Rand) in turn prevent any radical changes in mine layout.

It must, therefore, be realised that further improvements can only be gradually introduced. The definitive progress shown in the past, however, gives rise to the hope that such improvements will be effected and that thereby the incidence of miners' phthisis will be further reduced.

THE NATURE AND SOURCE OF DUST IN MINE AIR, TOGETHER WITH A BRIEF REFERENCE TO THOSE OPERATIONS WHICH PRODUCE DUST

BY A. F. McEWEN (CHIEF CHEMIST AND SECRETARY TO THE TRANSVAAL CHAMBER OF MINES STANDING COMMITTEE ON DUST), AND J. BUIST (SENIOR DUST INSPECTOR, TRANSVAAL CHAMBER OF MINES)

NATURE OF ROCK FROM WHICH DUST IS FORMED

The Witwatersrand System in which the gold mines are situated consists of a thick body of sediments which are said to have been derived from the waste of the Swaziland System.

The gold occurs in what are known locally as banket reefs. These reefs, of which the three principal ones are the Main Reef, Main Reef Leader, and South Reef, are conglomerate beds of closely packed vein quartz pebbles having a mean diameter of, say, from 2 to 3 centimetres, and bound together by a hard siliceous matrix.

These beds vary in thickness from a few inches to 6, 10 and even more, feet, and in the main they lie conformably with the adjoining strata, which may be described as a hard silicified quartzitic sandstone.

On the Central and West Rand the characteristics of the strata are much the same on both sides of the reefs. On the Far East Rand, however, the strata upon which the reef lies is of a finer grain and less siliceous than elsewhere, and is known locally as footwall shale.

The matrix of the banket contains a number of minerals, etc.[1], including osmiridium, and, as a curiosity, diamonds, but the most plentiful mineral is pyrites. The amount of pyrites contained in the reefs varies from place to place from about 1 per cent. to about 5 per cent., and averages in the neighbourhood of 3 per cent.

[1] Cf. R. B. YOUNG, Professor of Geology and Mineralogy at the University of the Witwatersrand: *The Banket of S.A. Gold Fields.*

The following are typical analyses of the reef and country rock at various places on the Rand:

FAR EAST RAND

	Hanging Wall (quartzite)	Reef (banket)	Footwall (shale)
	Per cent.	Per cent.	Per cent.
SiO_2	94.62	88.54	62.13
Al_2O_3	2.37	4.31	15.24
Fe_2O_3	1.14	1.55	9.14
FeS_2	—	1.31	—
CaO	0.56	0.57	0.45
MgO	0.15	0.61	7.85
Water	0.77	— (*a*)	4.27 (*b*)
	99.61 (*c*)	96.89 (*c*)	99.08 (*c*)

(*a*) Water not determined. (*b*) Loss on ignition. (*c*) Alkalis not determined.

CENTRAL RAND

	Country Rock (hanging and foot)	Reef (banket)
	Per cent.	Per cent.
SiO2	76.27	86.22
Al_2O_3	14.09	5.85
Fe_2O_3	4.71	1.97
FeS_2	—	2.19
CaO	0.23	0.90
MgO	1.64	0.78
Water	2.25	— (*a*)
	99.19 (*b*)	97.91 (*b*)

(*a*) Water not determined. (*b*) Alkalis not determined.

WEST RAND

	Country Rock (hanging and foot)	Reef (banket)
	Per cent.	Per cent.
SiO_2	86.18	88.86
Al_2O_3	5.27	2.51
Fe_2O_3	5.00	2.13
FeS_2	—	1.53
CaO	trace	1.02
MgO	1.07	1.06
Water	1.54	1.53
	99.06 (*a*)	98.64 (*a*)

(*a*) Alkalis not determined.

Nature of Dust in Mine Air

The following is an analysis of the dust accumulated in the Transvaal Chamber of Mines laboratory from thousands of routine sugar tube samples of air taken in various parts of every mine on the Witwatersrand (after treatment with hydrochloric acid to dissolve out the filter paper ash):

	Per cent.
SiO_2	80.69
Al_2O_3	8.58
Fe_2O_3	0.50
CaO	2.78
MgO	1.40
Loss on ignition	2.93 (*a*)
	96.88 (*b*)

(*a*) Includes organic matter, e.g. hairs from camel hair brush.
(*b*) Alkalis not determined.

The above analysis does not reflect the presence of certain other constituents usually found in mine air, as revealed on konimeter slides under the microscope—for instance, water residue salts and carbon.

The water residue salts are derived from the atomisation of the mine water used underground, and the carbon particles from the candles and acetylene lamps.

In the case of a sugar tube or gravimetric sample the water residue salts are washed out, and the carbon particles are eliminated by the subsequent ignition, along with the organic matter of the filter paper used.

A konimeter spot, on the other hand, when viewed under the microscope shows up all the particles of whatsoever nature which were in the air sampled, and which were caught on the slide.

Until quite recent years, and before means had been devised for the elimination of such contaminating particles, the counts of konimeter spots were liable to serious error. Accurate counting of the *silica* particles was oftentimes impossible. This matter, however, will be referred to elsewhere.

Sources of Dust

The principal operations which cause dust underground are:

1. Blasting.
2. The shovelling of broken rock.
3. The movement of rock in ore passes, ore bins, and the like.
4. Machine drilling.
5. Hand hammer drilling.

Physical Nature of Dust Arising from the Above-Mentioned Sources

1. *Blasting*

Blasting produces large quantities of dust of all sizes. The larger particles soon settle and are caught by damp surfaces or by water blasts in development ends. Most of the other particles are swept away by the mine ventilating currents during the interval which elapses between blasting time and the time for resuming work, and it may be said the residual dust which may be left in the mine air currents is chiefly fine dust of the order of about one micron.

2. *Shovelling*

This work produces some coarse particles of dust, but the average size of the particles is from 2 to 3 microns and under.

3. *Ore Passes, etc.*

Dust from these sources is readily recognisable under the microscope, since it is usually made up of particles of from 3 to 5 microns and over, mixed with but little fine dust.

4. *Machine Drilling*

The dust from this source is usually fine, that is to say up to only 2 microns, with a few coarser particles.

5. *Hand Drilling*

The dust from this source is similar in appearance to that produced by machine drilling, but konimeter counts are usually lower.

Amount of Dust in Mine Air

The following tabulations (A, B and C) show the amount of dust in various places, and in different years, as determined in the manner stated:

TABULATION A. — SHOWING THE AMOUNT OF DUST IN MINE AIR, EXPRESSED IN MILLIGRAMS PER CUBIC METRE, AS DETERMINED FROM SAMPLES TAKEN THROUGH THE MEDIUM OF SUGAR TUBES BY THE DUST INSPECTORS OF THE TRANSVAAL CHAMBER OF MINES IN VARIOUS PLACES IN EVERY MINE

Place	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929 [1]
Main travelling ways	2.8	1.7	1.6	1.6	1.2	1.4	0.8	0.9	0.7	1.3	0.7	0.6	1.1	0.9	0.5
Development ends	6.9	5.8	5.4	4.4	3.5	2.9	2.3	2.4	1.9	1.2	1.0	1.1	1.2	0.8	0.8
Shafts	3.6	4.7	3.7	2.9	4.8	4.9	2.5	2.8	2.1	0.4	0.8	1.3	1.2	0.9	0.7
Stopes	3.4	2.7	2.9	2.2	1.9	1.7	1.3	1.2	0.9	0.7	0.7	1.0	0.9	0.6	0.7
Ore passes and bins	4.4	4.0	4.2	3.7	2.9	2.7	2.1	2.2	1.8	2.0	1.6	1.8	1.9	1.5	2.0
Sundry	3.7	5.0	4.0	3.0	2.5	2.0	1.4	1.3	1.2	1.4	0.8	1.0	1.0	0.6	0.6
General average	4.9	3.9	3.8	2.9	2.4	2.0	1.6	1.6	1.3	1.1	0.9	1.2	1.2	0.8	1.0
Upcast	2.6	1.4	1.9	1.4	1.2	1.2	0.7	0.7	0.6	0.8	0.5	0.8	0.8	0.4	0.5
Downcast	—	1.4	1.6	1.3	1.1	0.9	1.0	0.6	0.7	0.6	0.5	1.0	0.7	0.3	0.6
Total number of samples analysed	1,860	5,155	6,359	7,547	7,641	7,206	6,885	4,632	4,855	1,071	2,390	2,587	2,843	2,663	1,351

[1] Jan. to Aug. inclusive.

TABULATION B. — SHOWING THE AMOUNT OF DUST IN MINE AIR, EXPRESSED IN MILLIGRAMS PER CUBIC METRE, AS DETERMINED FROM SAMPLES TAKEN THROUGH THE MEDIUM OF SUGAR TUBES BY THE MINE DUST INSPECTORS [1] IN VARIOUS PLACES IN EVERY MINE AND ANALYSED IN THE LABORATORY OF THE TRANSVAAL CHAMBER OF MINES

Place	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929 [2]
Main travelling ways	—	2.3	2.0	1.5	1.2	0.8	0.5	0.6	0.8	0.7	0.8	0.7	0.6	0.7
Developments ends	6.0	4.4	3.6	2.5	1.9	2.1	1.7	1.5	1.1	1.1	1.1	0.9	0.8	0.7
Shafts	5.8	3.3	5.5	3.0	3.6	2.5	0.3	3.2	1.8	1.5	1.4	1.1	1.2	0.8
Stopes	4.8	2.9	2.2	1.6	1.2	1.3	1.0	0.9	0.8	0.9	1.0	0.8	0.7	0.7
Ore passes and bins	5.5	3.9	3.4	2.3	1.9	2.0	1.6	1.7	1.6	1.6	1.6	1.2	1.1	1.1
Sundry	4.7	2.6	2.5	2.0	1.5	1.6	0.9	0.9	0.8	1.0	1.0	0.8	0.7	0.7
General average	5.2	3.4	2.8	2.0	1.5	1.6	1.2	1.2	1.0	1.1	1.1	0.9	0.8	0.8
Upcast	3.4	2.1	1.6	1.2	0.7	0.8	1.1	0.5	0.6	0.7	0.7	0.7	0.6	0.6
Downcast	5.5	1.8	1.9	1.1	0.9	1.2	0.5	0.7	0.6	0.6	0.7	0.8	0.7	0.6
Total number of samples analysed	5,261	14,362	27,460	27,508	25,821	23,739	16,259	24,709	25,268	24,616	25,796	26,212	26,228	15,195

[1] Appointed under Mining Regulation No. 161/10. [2] Jan. to June inclusive.

TABULATION C. — SHOWING THE AMOUNT OF DUST IN MINE AIR, EXPRESSED IN PARTICLES PER CUBIC CENTIMETRE, AS DETERMINED THROUGH THE MEDIUM OF KONIMETER SPOTS TAKEN BY THE DUST INSPECTORS OF THE TRANSVAAL CHAMBER OF MINES IN VARIOUS PARTS OF EVERY MINE

	1919	1920	1921	1922	1923	1923	1924	1925	1926	1927	1928	1929 [1]
Illumination	Light ground					Dark ground						
							Subdued reflector light					Full reflector light
	1.4 Condenser					1.2 Condenser						
Treatment	None											
					Acid vapour							
										Acid immersion		
												Ignition
Development ends	490	324	211	268	385	623	498	351	306	138	78	166
Shafts	468	303	303	167	261	361	420	242	378	120	78	109
Stopes	270	165	128	111	182	319	384	267	251	121	63	135
Ore passes and bins	240	129	155	154	185	289	356	240	246	146	105	247
General average	318	192	163	149	230	387	409	284	263	128	73	159
Intake air										106	47	89
Total number of spots	6,218	5,916	6,062	4,373	4,695	3,526	1,064	2,240	2,367	2,660	2,270	1,301

[1] Jan. to Aug. inclusive.

TABULATION D. — GIVING A FEW TYPICAL ANALYSES OF MINE WATERS EXAMINED IN THE CHAMBER OF MINES LABORATORY

Locality	Far East Rand			Central Rand			West Rand		
Appearance	Cloudy	Muddy (rust)	Clear	Muddy	Turbid	Cloudy	Muddy	Cloudy	Clear
Reaction	Alkaline	Acid	Alkaline	Acid	Acid	Acid	Acid	Alkaline	Alkaline
Per cent. H_2SO_4	—	.003	—	.012	.026	.023	.042	—	—
Per cent. NaOH	.003	—	.002	—	—	—	—	.030	.004
Insoluble mineral residue: grammes per litre	.149	.054	.016	.298	.046	.026	.051	.050	.030
Particles under 12 microns: grammes per litre	.052	.018	.004	.070	.014	.009	.015	.028	.006
Percentage of particles under 12 microns	35	33	25	24	30	35	29	56	20
Remarks	Unsuitable	Unsuitable. Requires clarification	Very good	Unsuitable	Passable	Very good	Unsuitable. Requires clarification	Passable	Very good

Water Used for Dust Prevention and Allaying

The Mining Regulations lay it down that the manager shall, for dust prevention and allaying purposes " . . . . provide an adequate and constant supply of water which is clear and odourless . . . . ", and the Transvaal Chamber of Mines Standing Committee on Dust laid it down in 1916 that water containing more than 0.05 grammes of insoluble mineral residue per litre should not be used with water fed drills or atomisers, and when water was so used it should be periodically analysed in the Chamber's laboratory.

Tabulation D gives a few typical examples.

Nature of a Day's Work Underground

The work performed underground by a European will, of course, vary in accordance with the class of occupation in which he is employed. It may, however, be said that the European miners on these fields are occupied mainly in directing and supervising the work of natives, and it is proposed herein to follow the course of a day's work of a man engaged in ordinary mining, pointing out where the various operations produce dust, and making brief reference to the methods employed for its suppression.

When a miner enters his working place his first duty is to ascertain whether it is safe, and, if not, to cause it to be made safe. His next, and really simultaneous duty, is thoroughly to wet the roof and sides for a distance of 25 feet from where any work is to be performed. Both these operations at first, especially where water blasts are not used, raise a certain amount of dust, in the same way as water applied to a road from a watering cart tends to stir up dust.

In making safe some mines have used hollow punch bars attached to a water hose, so that water under pressure emerges from near the end of the bar. These bars, however, are not popular with the miners since they are not so readily handled, and since there is a tendency for the water to run back down the arm of the operator.

A place having been made safe in accordance with the various provisions of the Mining Regulations, the ordinary work of drilling, shovelling, and, if necessary, timbering, is commenced.

Most of the dust caused by drilling escapes during the small interval of time occupied in starting a hole, say during the drilling of the first inch or two. This escape can be considerably reduced by playing from a hose a stream of water on to the rock being drilled, in addition to the ordinary supply which comes through the drill steel.

The following figures, which represent the average of a considerable number of special tests, reflect this reduction:

	Particles per cubic centimetre
Dust found in collaring when extra hose is not used .	75
Dust found in collaring when using extra hose . . .	49

After the miner has marked out the holes to be drilled and generally started his natives to work, he proceeds to perform sundry other duties, namely, the collection of his supply of explosives from the shaft station; the preparation of his charges; the marking of his native labourers' work tickets, and so on, exercising in the meantime a certain amount of supervision on the progress of the work generally.

The following time studies of certain classes of underground men were made during from May to August inclusive 1926 at the request of the Mines Department, and will serve to give an idea of how these classes of employees occupied an average shift:

	At stations and travelling to and from working place	Inspecting hanging and generally supervising at the face	At miners' box	Charging and lighting up	Total
	Percentage of total time				
Shaftsinkers	9.7	55.1	21.8	13.4	100
Developers	11.4	44.3	28.5	15.8	100
Machine stopers	12.2	58.6	17.4	11.8	100
Average	11.3	51.6	23.2	13.9	100

There has been no material alteration in methods of working since the dates upon which these studies were made, and they can be taken as representative of present day conditions.

After each hole has been drilled, and some time before the end of the shift, it is necessary that the holes shall be thoroughly cleaned out before the charge of explosives is put into them. Some miners cause each hole to be cleaned out immediately after it is drilled; others wait until just before charging time.

Until recently this cleaning out was done by compressed air applied through a pipe to the bottom of the hole for the purpose of blowing out all the mud and water in it. The more recently introduced method is first to wash out the holes with water under a considerable pressure through a pipe and then to dry the holes by causing the water to be sucked out by an ejector using a water jet as its source of power. By this method no compressed air is used, and less dust is projected into the mine air.

The following figures, which again represent the average of a number of tests, show the different amounts of dust produced by the two methods:

	Milligrams per cubic metre
Dust found in blowing out 5 holes with air blow pipe . .	45.9
Dust found when cleaning the same number of holes with water method	1.7

In considering these sources of dust, however, it must be remembered that either method occupies but a relatively short space of time, and that if, as is usually done, the sequence of blowing out the various holes is arranged in a direction against the ventilating current, the dust caused by the operation is quickly removed and does no harm to anyone.

While drilling is in progress the other operations of mining, such as shovelling the broken rock and loading it into trucks; timbering; track laying; pipe laying; track cleaning, and so on, are also performed. The Regulation already referred to, which requires everything within a distance of 25 feet from a point at which work is being done to be wetted and kept wet, has the effect in practice to cause in stoping the area between the whole length of the stope face and a distance therefrom of 50 or more feet to be wetted and kept wet, and in development work that practically the whole length of the heading shall be so treated. This being the case, the operations referred to, with the exception of the handling of the broken rock, cause little or no dust.

Various methods of handling the broken rock are in vogue to suit different conditions, the dip of reef, etc., but ultimately in all cases the ore is loaded into trucks and taken to ore passes and/or ore bins, whence it is loaded into the shaft conveyances and hoisted to the surface. Although the rock is kept wet during the process of handling and loading it can readily be understood that these processes cause a certain amount of abrasion of the rock and a consequent escape of dust. Particularly is this the case in ore passes where the rock has to fall, roll or slide through considerable distances, and where the rock is being tipped from or loaded into trucks or other conveyances. In these cases a successful way of combating the dust is to provide sprays and to ensure as far as practicable that the ore passes, bins, etc., shall never be entirely empty, but shall always contain enough ore to prevent a free current of air which in passing through them might carry the dust into the main ventilating currents of the mine; also to provide a secondary ventilation system which by means of suitably sized pipes will draw off the dust and by-pass it into the return airways, or if this is not possible, into an air filter of some kind.

Various types of filters have been tried, and while some of them have proved moderately efficient as dust traps, the expenditure of power in relation to the quantity of air filtered is so great that they are only used in places where the dust-laden air can be treated in no other way. One such filter consists of several large sheets of moist flannelette through which the dust laden air is forced at low velocity by a fan. In some cases old workings are used as filters, with excellent results, but such use is not always practicable.

METHODS FOR DETERMINING THE DUST IN MINE AIR, AS PRACTISED ON THE WITWATERSRAND

BY JAMES BOYD, A.R.T.C. (GLAS.), F.I.C., F.C.S., A.M.S.A.I.E.

To the best of our knowledge the first determinations of dust in mine air on the Witwatersrand were carried out for the Miners' Phthisis Commission of 1902, with the following results:

Place	Dust in milligrams per cubic metre
Face of drive	424
do. do.	192
do. do. behind spray	42
100 ft. from face after blast	83
End of drive 5½ hours after blast	43
Stope	14
Stope	32
Raise	164

In 1910 the East Rand Proprietary Mines found as much as 1,500 milligrams in a drive.

In 1911 the systematic determination of dust was begun by the Consolidated Gold Fields Group. The method adopted was a gravimetric one, a known quantity of the mine air being drawn through a column of pure sugar, the sugar being then dissolved in distilled water, and the dust filtered off, ignited and weighed. The dust-laden air was aspirated through the sugar (which was contained in a tube) by various methods, the one generally adopted being to use a double-acting suction pump.

The capacity of the standard pump is about 3 litres per double stroke, the pump being calibrated against a standard wet meter. The tube used to contain the sugar is made of thick walled glass tubing, 5 inches in length by $1^1/_4$ inches in diameter, fitted at the top with a solid rubber cork, and at the bottom with a one-holed rubber cork, through which passes a piece of glass tubing $^1/_2$ inch in diameter. At the bottom of the sugar tube is placed a small piece of cotton wool, this being used to prevent the sugar being drawn out in sampling. The sugar used is of such a size that it will pass a ten-mesh sieve and remain on a twenty-mesh sieve, and 40 grammes of the sugar is used per tube.

In taking a sample the tube is connected by a length (usually 6 feet) of pressure tubing to the inlet of the suction pump, and the required volume of air aspirated. This volume depends on the dustiness of the air, but is usually $^1/_3$ to $^1/_2$ cubic metre.

The tube is held at about the height of a man's mouth, and the sampling is done to windward of the pump, the tube being moved about so as to obtain a representative sample. After sampling, the tube is recorked, numbered, and a record made of the place sampled and the work in progress. The tube is then returned to the laboratory for analysis.

Up to 1913 all the dust found in a sample was regarded as dangerous, and was returned as total dust. The research of Dr. J. McCrae, however, proved that in the ash of a silicotic lung it was only the very fine dust that was found, the particles ranging in size from 12 microns downwards.

As the sugar tube determinations were of all the dust in the air, it became necessary, therefore, to devise some method of separating the coarse from the fine dust.

In 1915 Dr. J. Moir published details of a method for the separation of large and fine quartz particles. The method consisted of allowing dust in suspension to settle in water for a period of time, calculated from the size of the particles and from the rate of fall of quartz particles when suspended in water. The formula is as follows:

$$V = \frac{7D^2}{100000}$$

where V = velocity of fall in cm. per second.
D = diameter in microns.

In practice, the procedure to settle out particles above 12 microns in size was to allow the well-mixed suspension of dust to settle for four minutes for each centimetre of height of the liquid in a straight-sided beaker, siphon off the supernatent liquid (containing the fine dust in suspension), make up the residual liquid to the original bulk, allow to settle for two minutes for each centimetre of height, siphon off, mix the two siphoned-off liquids, filter and weigh the dust.

In dealing with large numbers of samples, the time involved in this process was very great, and recourse was made to a mechanical method. It became possible to obtain very fine screening of some 350 mesh. A small truncated cone was made, the screening forming the base of the cone, and the sugar solution containing the dust was filtered through the cone on to a fine filter paper. The cone is then washed free of sugar solution, removed, and the filter paper containing the dust is then incinerated in a crucible, cooled, weighed, and the weight of dust determined.

As all sugar contains a certain amount of inorganic dust, it is necessary to make an allowance for this as well as for the weight of the filter ash. This is done by running a number of blank sugar tubes, which are treated in the same way as the tubes containing dust and the weight of dust found is taken as the weight of dust in the sugar plus the weight of the filter paper ash, the amount usually being about 0.7 milligrams per sample. The amount of dust found in mine air is returned as milligrams per cubic metre.

The method described above gives the weight of dust in a given quantity of air. It is, however, necessary to have a knowledge of the number of particles of dust in the air. This can be determined in a gravimetric sample by counting the dust in an aliquot part of the solution by means of a Haemocytometer or similar instrument; but this is a tedious method.

In 1916 Sir Robert Kotze, Chairman of the Miners' Phthisis Prevention Committee, devised an instrument to enable the particles of dust in mine air to be counted. This instrument, known as the *Konimeter*, consists of a valveless cylindrical suction pump of a cylinder capacity of 5 to 10 cubic centimetres. In this instrument a piston is depressed and held by a catch, and when it is released a volume of 5 cubic centimetres of air is sucked in through a nozzle, which is tapered and smoothly bored, with an orifice diameter of 0.6 millimetre. The air sucked in impinges on a glass slide which is placed 0.5 millimetre from the nozzle. The slide is made by cutting an ordinary microscope slide in half, and is held in position over the nozzle by means of a spring, the jet itself being surrounded by a rubber ring about 16 millimetres in diameter. This forms, with the slide in position, a small air-tight chamber. The slide may be moved over the chamber so that samples of dust may be taken. The slide may be coated with a very thin coating of vaseline or glycerine jelly, or, if the sample is being taken in moist air, may be uncoated with any adhesive. The velocity of the air when it leaves the nozzle should be not less than 30 metres per second. To count the particles of dust in the spot, the slide is examined under a microscope, using a 16-millimetre objective, and an eye-piece of high power. An eye-piece micrometer ruled in sectors is used, the most usual sectors being either 9° or 18°. The spot is counted vertically and then the eye-piece is rotated through 90° and the spot counted again, the sum of the two counts giving the number of dust particles when 5 centimetres of air has been impinged.

A modified form of Konimeter is also used. In this instrument the glass plate on which the dust is caught is made circular and fitted into a toothed wheel which engages a pinion. By means of this device the plate is made to revolve under the jet and as many as sixty spots can be taken on the one slide. When the plate is removed from the Konimeter it is fitted into a special holder on the stage of the microscope, and by means of a toothed pinion is revolved under the objective so that each spot in turn comes into focus and can be counted.

When the Konimeter was invented, counting was done by means of ordinary reflected light, but it was soon found that, as the particles of dust are extraordinarily minute, they could not all be counted by this means. After much experimenting a method was evolved which is a modification of dark ground illumination. The method has for its object the securing of contrasts, and therefore a spot is used which allows the maximum illumination. In practice this is obtained by placing a dark ground spot of 10 millimetres diameter immediately below the condenser. This cuts out the central portion of the light pencil and allows the particles of dust to stand out clear, bright and easily countable. Illumination is obtained by using a 100 candle power $^1/_2$-Watt ground glass bulb, which is placed about 9 inches from the mirror.

Just as the gravimetric sugar tube collects all the dust in the air, irrespective of size, so does the Konimeter collect the dust irrespective of kind, and irrespective of its nature.

It has been pointed out by Dr. Mavrogordato that all instruments delivering air at a high velocity through a narrow jet bring in the condensation principle, and that the resultant spots are not only precipitation spots but also condensation spots, so that if the moisture in the air contains salts in solution, these will materialise as visible particles when the spot on the Konimeter is examined under the microscope. This does happen in the sampling of mine air by the Konimeter, and has been a source of error and of great trouble in Konimeter work on these fields.

Water used for dust allaying almost invariably contains soluble salts, and, as the air underground is more or less saturated with moisture, a Konimeter spot contains salts of sodium, calcium and iron. The Konimeter appears to exert a selective action in its collection of dust particles, and these are always of very small size. The soluble salts in the moisture in the air crystallise out in very minute crystals, and are nearly always indistinguishable from the quartz particles. Here then we have a source of very considerable error.

In addition, the illumination of the underground workings is by means of acetylene lamps and candles. Acetylene, as is well known, burns with a smoky flame, and large amounts of carbon in a very fine state of division are liberated, so much so that the gravimetric or sugar tube sample is often stained black by the carbon. The carbon particles by semi-dark ground illumination appear bright and shiny like the silica particles, and it is impossible to differentiate the one from the other. As far as our knowledge goes, carbon particles are not dangerous when breathed into the lung, and as in some places they are present in very large quantities in mine air, if counted in the Konimeter sample with the silica dust, an entirely wrong idea of the dangerousness of that particular sample of mine air would be obtained. Here there is another source of error in counting dust particles.

Experiments were conducted for some time in an endeavour to eliminate the soluble particles from the Konimeter samples, and a method devised by Mavrogordato, Moir and Ray proved satisfactory. These investigators found that most of the soluble particles could be removed by the action of hydrochloric acid vapour, which did not touch the silica.

The method adopted was to insert a watch glass over the spot, the watch glass having in its centre a small segment of filter paper saturated with a 15 per cent. solution of hydrochloric acid. In the case of spots on circular slides a rubber ring is placed round the periphery of the slide and a spare glass slide with the saturated filter paper in the centre placed on top of the ring, thus forming a small chamber with an atmosphere of hydrochloric acid gas. By this means most of the soluble salts were dissolved, but, unfortunately, not the carbon particles.

In 1927 McEwen and Thompson tried immersing the whole slide in a dilute solution of hydrochloric acid, washing in distilled water and drying. Instead of this somewhat drastic treatment removing the whole spot, they found that on examination under the microscope the particles on the spot shone up clear and bright with no trace of contamination by either carbon or soluble salts; the silica in fact looked clean and polished.

Many experiments were made to see if there were any loss of silica particles, but the results in many cases showed an increased count after treatment, as if some of the silica particles had been masked by carbon in the original count.

In 1925, on my suggestion, an attempt was made to eliminate carbon from the spots by ignition, using heat-resisting glass in the slide, but unfortunately it was not then possible to obtain a sufficiently transparent glass.

Recently it has been found possible to obtain a glass with heat-resisting properties which is also transparent under the microscope and free from flaws. McEwen and Thompson have made a large number of experiments with encouraging results. The slides are made of Chance's heat-resisting glass. On to the centre of the slide is poured a few cubic centimetres of the acid, and this is allowed to spread all over the slide covering the spots. The slide is then immersed in a basin containing distilled water, the washing being repeated twice, and finally the slide is immersed in hot distilled water and allowed to dry. The slide is then placed on a smooth fireclay tile in a cold gas muffle, and the gas lit. The mufflle is kept at a dull red heat for thirty to twenty-five minutes, then the gas is turned off and the slide allowed to cool in the muffle. The silica particles when examined under the microscope after this treatment are clear and bright, and in many cases show a much larger count than before treatment.

This new method represents a very great advance, and enables more reliance to be placed on the accuracy of Konimeter samples.

Systematic Dust Sampling on the Witwatersrand

Previous to 1913 no attempt had been made to determine systematically the amount of dust in the air of the mines of the Witwatersrand. In December of that year the Miners' Phthisis Prevention Committee, which had been appointed by the Government, caused the first dust survey of the mines to be carried out.

The samples were all taken by the gravimetric method, and gave the following results:

	Milligrams per cubic metre
General average	5.4
Drives	6.1
Raises	9.1
Winzes	5.0
Ore bins	5.5
Stopes	4.2

In May 1914 the Chamber of Mines established a department to investigate the dust conditions of the mines, and to suggest methods of preventing the formation of dust and its dissemination into the air of the mines. Visits were paid to each mine, and samples taken in as many of the working places as possible. Tests were made of various kinds of work likely to produce dust, and suggestions made for bettering conditions.

Since 1914, fifty-eight systematic dust surveys were made, showing the following results:

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
General average	4.9	3.9	3.8	2.9	2.4	2.6	1.6	1.6	1.3	1.1	0.9	1.2	1.2	0.8	1.0
Development	6.9	5.8	5.4	4.4	3.5	2.9	2.3	2.4	1.9	1.2	1.0	1.1	1.2	0.8	0.8
Stopes	3.4	2.8	2.9	2.1	1.9	1.6	1.2	1.2	0.9	0.7	0.7	1.0	0.9	0.6	0.7
Ore bins	4.4	4.0	4.2	3.7	2.9	2.7	2.1	2.2	1.8	2.0	1.6	1.8	1.9	1.3	2.0
Percentage over 5 mg.	27.0	23.0	20.0	13.0	10.0	8.0	4.0	4.0	3.4	2.5	1.7	1.1	1.2	1.2	1.9

It will be noticed from the above table that there is a steady diminution in the quantity of dust found in the various sections into which mine work is divided. Taking 5 milligrams per cubic metre as the danger mark, it will be noticed that whilst in 1915 27 per cent. of the samples were above that limit, it had fallen in 1928 to 1.2 per cent. and in 1929, owing to some high samples at ore bins, was 1.9 per cent.

In 1916 it was decided to appoint an official on each mine to investigate and report on the dust conditions, as it was recognised that the staff of inspectors appointed by the Chamber of Mines could not be expected to pay sufficient attention to all the working places on the mines. These inspectors were expected to pay surprise visits to see that things generally were in good condition.

The mine officials took samples in the same way as the Chamber's officials, and all the samples were analysed in the Chamber's laboratory. The following table shows the more important of the results obtained:

	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929 (6 mths.)
General average	5.2	3.4	2.8	2.0	1.5	1.6	1.2	1.2	1.0	1.1	1.1	0.9	0.8	0.8
Development	6.0	4.4	3.6	2.5	1.9	2.1	1.6	1.5	1.1	1.2	1.1	0.9	0.8	0.8
Stopes	4.8	2.9	2.2	1.6	1.2	1.3	1.0	0.9	0.8	1.0	0.9	0.8	0.7	0.7
Ore bins	5.5	3.9	3.4	2.3	1.9	2.0	1.6	1.8	1.6	1.6	1.2	1.2	1.1	1.1

It will be noticed that the improvement in dust conditions indicated by the samples taken by the Chamber inspectors is corroborated by those taken by the mine inspectors.

Konimeter Samples

Since 1919 Konimeter samples have been taken as a matter of routine at the same time as the gravimetric samples.

Until June 1923, all the samples were counted by light ground illumination, with the following results:

	1919	1920	1921	1922	1923
Development	490	320	211	270	390
Stopes	270	165	130	110	180
Ore bins	240	160	150	150	190
General average	318	190	160	150	230

As before stated, dark ground illumination was introduced in July 1923, and the following results were obtained:

	1923	1924	1925	1926
Development	620	480	350	310
Stopes	360	390	260	250
Ore bins	280	350	250	250
General average	380	410	280	270

In 1927 the McEwen-Thompson method of treating the slides for the removal of soluble particles and particles of carbon was introduced, with the following results:

	1927	1928
Development	132	78
Stopes	119	62
Ore bins	142	105
General average	125	73

In 1929 the ignition method of treating the slide was introduced and in addition the spots were counted by using the full reflectors of the microscope instead of subdued light.

Results	1929 Particles per c.c.
Development	165
Stopes	135
Ore bins	247
General average	159

Conclusions

The figures given show that there has been a vast improvement in the amount of dust present in mine air in 1929 as compared with 1914.

It may be asserted that neither of the two methods of sampling dust in mine air used on the Witwatersrand are methods which can claim any scientific accuracy. The errors which can be, and are, introduced through no fault of the operator are such as to render any claim to real accuracy untenable. The gravimetric method, sampling as it does all sizes of dust in the air, can easily be made to show very serious dust conditions by the presence of a few large (in the microscopic sense) particles of dust, whilst innumerable small dangerous particles of very light weight will not be reflected in the results obtained. The difficulty of separating the gravimetric sample into large (in the microscopic sense) and fine dust is so great that it is not practicable in ordinary routine work. On the other hand, as an indication of the dust conditions, the gravimetric method is useful and has done good work. The vast improvement in underground conditions on the mines of these fields can be traced to the results of gravimetric sampling as showing the condition prevailing.

Despite its faults and errors, the fact that, by the same method as was used in 1914, the average dust content of mine air has fallen from over 5 milligrams per cubic metre to round about 1 milligram, is an indication of the good work performed as the result of using the gravimetric method to call attention to bad conditions.

The Konimeter method has also its faults and errors, some of which have been already mentioned, such as its showing up all dust, whether dangerous or not, and its liability to contamination by carbon particles.

The result of long and painstaking research work indicates that it may be possible in the future to obtain a sample by the Konimeter method which will be a true indication of the amount of dangerous dust in the mine atmosphere.

In the meantime we can say that by using both methods we can obtain results which, if interpretated in a relative manner, give us a good indication of the dustiness, and consequently of the dangerousness from a phthisis-producing point of view, of the air of the mines. By using these methods and remembering that neither give accurate results, but rather results which are only an approximation to absolute accuracy, we can still hope for further improvement in the dustiness and ventilation of the mines.

MEASURES FOR PREVENTING THE FORMATION OF DUST, AND PRECAUTIONS DESIGNED TO PREVENT PERSONS INHALING SUCH DUST AS MAY BE FORMED, AND THE REGULATIONS RELATING THERETO[1]

BY MALCOLM FERGUSSON, CHIEF INSPECTOR OF MINES, UNION OF SOUTH AFRICA, AND WALTER SCOTT, ASSISTANT CONSULTING ENGINEER, CENTRAL MINING-RAND MINES GROUP OF MINES

Miners' Phthisis Commission's Finding

Little, if anything, had been done in the way of taking precautions to prevent persons from inhaling dust before the sitting of the Miners' Phthisis Commission in 1902-1903.

The finding of the Commission was that miners' phthisis was contracted as the result of miners inhaling dust-laden air, and the disease was to be found chiefly among rock-drillers in development ends, especially when employed on raising.

Sources of Dust Production

The chief sources of the dust inhaled by developers were as follows:

(*a*) *The drilling of dry holes* in raises and drive ends. In the former all the holes were drilled dry, in the latter the two top holes were drilled dry as well as the bottom cut holes. Holes inclined downwards had water poured into them by hand sufficient to prevent the drill from sticking. Samples of air taken close to the rock drill machine whilst boring a dry hole showed that there were 0.185 and 0.0839 grains per cubic foot of air respectively, and an

[1] The following notes will serve to give the reader a working knowledge of the steps which have been taken on the Witwatersrand on the subject matter of these notes. They will be found in some respects to overlap certain portions of the Historical Review of Mining Conditions on the Witwatersrand, p. 107, but this is clearly unavoidable.

analysis of air taken in a raise in similar circumstances gave as a result 0.072 grains per cubic foot.

(*b*) *The method of blasting* in development ends considered, at that time, to be necessary for obtaining good results.

It was the practice of the miner to charge up the cut holes completely, and the remaining holes partially, then to blast the cut and return to the end after a very short interval; he then completed charging up the remaining holes, i.e. put in the primer cartridges and tamped the charge, and blasted the round. Miners were even known to return after blasting the round to see how it had broken.

Precautions

Among the first precautions taken to prevent the dust formed in drilling and blasting from being inhaled by the miner, was the use of inhalers and respirators.

Dr. Aymard's inhaler was a close-fitting mask placed over the nose and mouth of the rock-drill operator. This mask was connected to the air-cock operating the machine, whereby compressed air was supplied to the miner by means of a light flexible metallic tube about 6 inches long. It was not necessary for the mask to fit perfectly as the constant pressure of air prevented the ingress of dust. The objection raised to this form of inhaler was: first, the range of the wearer's movements was limited to the length of the flexible tubing; second, air from the compressors, at that time, occasionally contained dangerous quantities of CO and CO_2 due to having unsuitable lubricating oil in the compressors.

There were various makes of *respirators* used by the miners. The essential points which a respirator has to fulfil to be considered satisfactory were as follows:

(*a*) It must fit closely to the face so that the whole of the inspired air would pass through the filtering material and not short-circuit between the face and the side of the mask.

(*b*) The filtering material must be capable of arresting all the minute angular particles of dust in the air, but should not impede respiration.

(*c*) The mask must be fitted with an outlet valve through which the expired air can escape freely.

From the original trials made with respirators, they were considered to have sufficient merit to permit the miner to return to the end of a drive shortly after blasting the cut to complete blasting the round, provided he wore a respirator. This was embodied in an addition to Regulation No. 146 of the Mines and Works Regulations gazetted on 29 December 1905, viz.:

(6) After blasting in any end, raise or other place, no person shall return to that place until after the lapse of at least half-an-hour unless the air in such place has been cleared of the dust and smoke arising from such blasting, by efficient ventilation or other special means, or unless an efficient respirator or other apparatus is used to prevent the inhaling of such dust or smoke.

Also Government Notice No. 1278 of 1908, 146 (11), permitted a miner to enter a development end containing dust and fumes provided he wore a respirator. This practice was permissible until 30 October 1913.

The use of the respirator seemed a simple and effective solution of the whole matter, but it proved impracticable. The miners as a whole were averse to the use of respirators chiefly, perhaps, on account of the discomfort attending their use, e.g. extra effort required to inhale through the filtering material when working hard, and interference with speech and smoking. The valve was usually made of mica and got out of order very easily, so that the miner invariably replaced it by a piece of sponge. This was objectionable as it did not permit of the free escape of the CO_2 and moisture exhaled.

It was eventually ascertained that the filtering material did not arrest the very fine dust particles in size 10 microns and under, which were the most harmful, and the use of respirators was rapidly abandoned.

It is interesting to note here that in 1902 the Transvaal Chamber of Mines advertised a competition in papers in the United Kingdom, Europe, Australia, South Africa and America and offered prizes for the three best suggestions and devices for the prevention of miners' phthisis. There were 229 competitors' suggestions as under:

1. Respirators	41
2. Dust extractors and hoods	35
3. Water drills	9
4. Jets delivering water inside the hole	4
5. Jets delivering water at the mouth of the hole	60
6. Sprays	22
7. Atomisers	6
8. Medical	15
9. Miscellaneous	37

The judges condemned as quite impracticable and useless Classes 1, 2, 8 and 9, but the others are all in general use in some form or other.

Fumes and Dust from Blasting

From the evidence given before the Miners' Phthisis Commission in 1902-1903, it is evident that up to that time there had been few restrictions of blasting operations, and that persons working underground had been very frequently exposed to smoke and fumes; this latter state of affairs was particularly marked at the end of the one shift and the beginning of the other.

The Commission in its report did not lay stress on the necessity of avoiding exposure of men to blasting smoke in the mine, except in the case of miners returning to dead-ends immediately after blasting. The danger from dust produced by blasting was not then fully realised, and, although progress was made in allaying dust produced by machines, etc., by the use of water, it took some years before the effects of dust from blasting were finally controlled. The following extracts from reports of inspectors of mines clearly show that even as late as 1911 the conditions on some of the mines were still very bad:

> In 1908-1909 it was a common practice on a certain mine to send the night-shift down against the day-shift coming up—naturally the night-shift had to inhale smoke from blasting.

Occurrence in 1911 and the years immediately preceding it:

> While taking dust samples in a stope about 6 p.m. in an atmosphere which was full of smoke, the night-shift arrived to begin work, and I understand that this was a daily occurrence.

No real advance was made until the Medical Commission issued its report in 1912, and definitely concluded that not only men working rock drills, but all men working underground were liable to contract miners' phthisis.

From this conclusion it was perfectly clear that the problem had resolved itself into not only allaying the dust produced by drilling machines and the removal of the broken rock, but reducing the dust content of the whole mine atmosphere, which was permeated with very fine dust particles, blasting operations being the most prolific source of dust and the most difficult to contend with. It was impossible to reduce the dust in the air created by blasting to a safe limit, and the only method to overcome its deadly effect was to remove the men before the smoke enveloped them and to keep them out of the mine until the fumes and dust were dissipated.

Double Shifts

One factor which had a very marked effect on the health of the miner was the double shift worked on all the mines of the Witwatersrand, i.e. a complete cycle of mining operations, cleaning, drilling and blasting, was performed on two shifts in the twenty-four hours. Owing to the duration of each shift being nine and a half to ten hours, there was insufficient time between the shifts to permit of the smoke and fumes from blasting operations to be cleared out of the mine before the arrival of the following shift, and almost invariably the on-coming shift was exposed to smoke and fumes. On Saturdays the position was even worse, as the afternoon shift was lowered immediately after the blasting of the morning shift; this had to be done in order to get a full shift in by midnight, as it was, and still is, illegal to work on Sundays.

When it became known that these conditions were exceedingly injurious to health, the necessary change-over to single shift could not be effected at short notice, but had to be done gradually.

Generally all the stope faces in the mine were being worked, and to obtain the required tonnage for the mill these faces had to be drilled and blasted twice in twenty-four hours; to maintain the stope faces, development ends were being pushed ahead on double shift.

Summing up the position, the mines had to continue double shift until such time as sufficient faces were available to permit the breaking of the necessary tonnage to keep the mill supplied on the one shift only.

Alterations Necessary for Single Shift Working

A further factor which delayed the change-over was that the mines were only equipped for double-shift working. Considerable alterations and additions had to be made in the plant and in the mine itself, e.g. compressors had to be duplicated to meet the greater demand for compressed air. Hoisting arrangements could not cope with the full complement of men on the single shift; the capacity of ore bins underground was too small; the number of rock drills had to be increased, etc. Apart from the time required to effect these alterations, a large amount of capital had to be found before they could be carried out.

Progress of the Single Shift

In 1907 some of the mines resorted to what was virtually a sixteen-hour shift, i.e. two eight-hour shifts, the one shift following directly after the other, blasting operations being carried out at the end of the second shift only. This was undoubtedly a step in the right direction, as it gave an interval of eight hours for the smoke and fumes to clear away before the following shift was sent down.

The year 1910 registered a further advance, in that some of the mines were on single shift, blasting at the end of the shift, i.e. the major portion of the work in the mine was done on the day shift, with a limited complement of boys and men on night shift to do the cleaning out.

By 1913 the majority of the mines on the Witwatersrand had changed over to single shift, the full night shift of practically equal strength to the day shift having become a rarity.

There is no doubt that the elimination of the double shift was one of the most important steps taken to produce healthy underground conditions, as well as doing away with an unduly expensive night shift expressed in the following terms by a witness before the Mining Regulations Commission, 1907:

> Nearly all miners sleep underground on night shift, the average time slept being about four hours.

Duration of Shift

The duration of the shift also had a very important bearing on the health of the miner. It might almost be considered, other things being equal, as a measure of the amount of dust inhaled by the miner.

Prior to the Anglo-Boer War, miners were scarce, and the tendency was for contractors to take on as much work as was given to them; this entailed long hours underground, and it was not an uncommon practice for a contractor to have two gangs of natives working, one on day shift and the other on night shift. Although the latter practice eliminated itself as the mines became deeper and access became more difficult, nevertheless the tendency for contractors to work long hours underground persisted and became an established custom.

Up to 1909, the mines were still working shifts of ten hours' duration; the hours were, day shift 7 a.m. to 5 p.m., night shift 7 p.m. to 5 a.m. On the day shift the men were allowed one hour on the surface for lunch. In 1910 the hour for lunch was done away with, thus reducing the over-all period to nine hours. This was a very much better arrangement, as the men were hoisted an hour earlier; this gave them more daylight for outside recreation. It also increased the interval between shifts.

The nine-hour shift continued until Act 12 of 1911 was passed, limiting the hours of employment of persons underground.

Act 12, 1911

> 9. (1) No person employed to perform underground work in any mine shall work, and no person shall cause or permit any person so employed to work, underground for a longer period than eight hours during any consecutive period of twenty-four hours, or forty-eight hours during any consecutive seven days, exclusive of time occupied in going to or from the working place.

There is no doubt that the reduction of hours could only do good from the point of view of the miners' health, and, as far as reducing the amount of work done was concerned, had little effect, as it was balanced by closer supervision and improved organisation generally.

Difficulties were met with at first in arranging shifts and hours, but were finally overcome. The eight hours was from face to face, and this led to difficulties in regard to time spent underground by the miners, the contractors being only too willing to remain at work in order to get the best results, the increased overtime being attributed to travelling delays, etc.

Regulations

In order effectively to control and give effect to the eight-hour shift, the following Regulations were promulgated:

158. In addition to his other duties and responsibilities under these regulations, the manager shall:

(24) Provide on mines other than coal and base metal mines under section 9 (2) (*c*) of the Act:

(*a*) That a notice shall be kept posted up at each shaft head, showing the time within which shifts will be let down and hoisted up at the shaft head.

(*b*) That the average time in getting miners, as defined in Act 19 of 1912, from the shaft head to their working place at the commencement of their shift, and back again at the conclusion of such shift, shall together not exceed thirty (30) minutes per miner for any one shift. In special cases, after application made through the Inspector of Mines, the Minister may grant such extension of the period of thirty minutes as he may consider to be necessary. Notice of such application shall be posted up at the mine for fourteen days before the application is sent to the Inspector of Mines.

(*c*) That the mine overseer, shift boss or other official appointed by the manager for the purpose shall satisfy himself that no white person not exempt under section 9 (2) of the Act remains underground after the ordinary hoisting of persons employed on that shift is concluded, and shall record in a book to be provided by the manager, the name of any such white person so remaining underground, and the time when such white person reaches the surface.

The effect of these Regulations was to give the white man an average period of eight and a half hours underground, including travelling from the surface to his working place and back again.

Original Arrangement arrived at between the Transvaal Chamber of Mines and the South African Mine Workers' Union

That from 1 January 1918 the underground working week shall be forty-eight and a half hours bank to bank, the length of each shift to be counted from the first skip down to the first skip up, and the Saturday shift to be at least one hour less than the weekday shifts. (In practice the hours are eight and a quarter bank to bank on weekdays and seven and a quarter on Saturdays, with some minor exceptions, e.g. certain shaft sinkers and developers.)

These are the hours prevailing on all the Witwatersrand mines at the present time.

Conditions Prevailing in the Mines

Generally the adverse conditions which had to be overcome may be summed up as follows:

(1) All men on the outgoing shift were not hoisted before blasting took place, and were in the mine for some time after blasting operations had taken place, and in many cases were exposed to smoke.
(2) Some of the persons had to be hoisted in the upcast shafts, where the conditions were bad.
(3) The persons actually blasting were often unable to avoid the smoke from blasting.
(4) Promiscuous blasting was practised more or less throughout the shift.
(5) The oncoming shift was lowered before the air was sufficiently clear.

To overcome Nos. (1) and (2) the mines had to resort to hoisting as many men as possible in the downcast shafts.

Special cages and conveyances were made to hoist the workmen as quickly as possible before the smoke overtook them in the upcast shaft. Doors and regulators were put in to keep back the smoke or to deflect it. Mechanical ventilators were temporarily stopped to delay the arrival of smoke at the shaft; suitable waiting places were provided for the up-going shift and kept supplied with fresh air from the compressors.

No. (3) was overcome to a great extent by arranging the blasting of individual places in a suitable sequence commencing from the upcast side and travelling against the air currents.

No. (4): blasting, except where absolutely unavoidable and in isolated instances only, was confined to the end of the shift.

No. (5): blasting at the end of the day shift, and increasing the interval between that shift and the following oncoming shift, was finally overcome by doing away with the double shift and blasting at the end of the shift only.

The concentrated attention given to the problem of successfully combating miners' phthisis led to the carrying out of necessary experiments by individual mines. As the problem became better understood, the tendency was for successful innovations to be automatically adopted into general practice.

The progress of these changes is reflected in the history of the changes periodically embodied in the Mining Regulations.

Regulations

On the recommendation of the Miners' Phthisis Prevention Committee, the following Regulations were eventually framed, and were embodied in the amendments published on 30 October 1913:

61. No person shall work, or remain, or be permitted or ordered to work, or remain in any place in a mine, if the air contains dust smoke or fumes perceptible by sight, smell, or other sense.

101. (33) A ganger or miner . . . shall only blast at the end of the shift, except where necessary, and then only with the permission of the mine overseer or the shift boss.

158. The manager shall:

(4) Cause blasting operations and shifts to be so arranged that workmen shall be exposed as little as practicable to fumes and dust from blasting.

178.

(2) All Regulations referring to the prevention of miners' phthisis shall, so far as they concern coloured workmen, be translated into the more important native languages and kept posted up in the compounds.

The First Miners' Phthisis Prevention Committee investigated the extent to which men were exposed to the dust and fumes from blasting at the end of the shift, and dust samples were taken on all the mines for the purpose of determining the amount of dust present in the air breathed by the oncoming shift. They found that the air after blasting contained extremely large quantities of dust, and that the presence of smoke is a sufficient indication of the existence in such air of an amount of dust which is very dangerous to health. Five minutes in such an atmosphere has probably a worse effect than a full shift spent in drilling holes in a drive with water well applied. This indicated that very stringent measures had to be taken to prevent persons from being exposed to fumes from blasting.

Largely on the recommendation of the Miners' Phthisis Prevention Committee, further amendments were added to the Regulations and promulgated in 1917; their object was to improve the conditions in mines in respect of dust and ventilation. The following are those applied to prevent persons being subjected to fumes and dust underground:

60. In any mine included in the list of mines framed under section 2 of Act 19 of 1912 (mines in which miners' phthisis may be contracted):

(1) Blasting shall only take place once in every twenty-four hours, except as permitted under Regulation 106 (33), or for sinking vertical shafts, or after written permission has been obtained from the Inspector of Mines;

(3) No person shall blast or be permitted or caused to blast the cut and round separately on the same shift in the same development end.

106. (34) Shall . . . only blast at the end of the shift except for removing obstructions in ore passes or box holes, or for the purpose of making the hanging safe, or for blasting misfired holes in development faces, and then only with the permission, in each case, of the manager, mine overseer or shift boss.

158. The manager shall:

(4) Cause the times of the working shifts and of blasting operations in every section of the mine to be so arranged that workmen shall not be exposed to fumes and dust from blasting, unless this is unavoidable;

(5) Cause every person not engaged in blasting operations, or not required for the transport of the persons so engaged, to be hoisted to the surface or removed to the intake side of all places in which blasting is to be done, or to remain in a waiting place free from fumes and dust before blasting commences;

(6) Cause every person engaged in blasting operations or required for the transport of persons so engaged to travel to the surface in the downcast shaft, unless they can be removed from the mine before the fumes overtake them or can remain in a waiting place free from dust and fumes, until these have dissipated;

(7) Cause any person who is to work in the mine after blasting has taken place to enter the mine only after the places in which he has to travel or work are clear of fumes and dust, and after the expiry of an interval to be fixed for each mine by the Inspector of Mines;

(8) Supply to the persons who have to carry on blasting operations, lighting torches, which in burning evolve not more nitrous fumes, expressed in terms of NO_2, than one-half of 1 per cent. of the weight of substance burned.

161. (9) A shift boss or other official of at least equal rank shall be present underground at each working shaft at blasting time and shall not travel to the surface before the persons engaged in blasting operations.

(10) The manager shall, when the total number of persons employed underground, on any one shift, exceeds 1,000 persons, appoint one or more competent persons whose principal duty it shall be to examine and report to the manager on:

(*a*) All matters relating to the mine's water supply, its quality, distribution and use,

(*b*) The condition of the necessary appliances for using water at each working place, etc.;

(*c*) The dust sampling of the mine;

(*d*) The condition of the mine relating to ventilation and health, etc.

The manager shall, by letter, notify the Inspector of Mines of the person or persons so appointed from time to time, and the reports made by them shall be open to the inspection of the Inspector.

143. (2) (*c*) Any person who has knowledge of dust or fumes in the workings during working hours, etc., shall record the matter without delay in the record book.

(*d*) Verbal report of the above defective condition to be made to the shift boss or other official.

The following amendment was made as from 30 October 1913:

106. A ganger or miner who is the holder of a blasting certificate:

(33) Shall not enter or allow any person to enter an end, raise, winze or other close place after blasting within thirty minutes after putting the water blast in action, and then only if the air is free from dust smoke, and fumes perceptible by sight, smell or other senses.

The practice of returning only when the drive, raise or winze was free of smoke, although an advance on the previous practice, was still unsatisfactory, as it frequently happened that the water blast was out of order when the miner blasted, or the water blast was put out of commission by the blast; the miners were very unwilling to lose the round, and there was nothing to prevent the men re-entering before thirty minutes had elapsed or before the smoke had been cleared out of the drive.

The practice of blasting the cut and round separately on the same shift was prohibited by Regulation 101 (3) from and after 1 January 1915, except with special permission from the Inspector of Mines.

By this time a considerable number of the mines had discontinued this practice and were blasting cut and round together, or had made provision for the cut being blasted on the one shift and the round on the following day by increasing the miners' working ends.

One or two mines continued to blast the cut and round separately on the same shift, availing themselves of the special permission granted under certain restrictions.

Finally the practice was totally prohibited in 1917.

With the improvements in drilling machines and methods applied at the present day, very little footage is lost by blasting cut and round together.

The 1925 Annual Report of the Transvaal Chamber of Mines Standing Committee on Dust Sampling records a steady and progressive decrease in the average amount of dust found in mine air since 1915.

Referring to Regulation 158 (8), the Miners' Phthisis Prevention Committee considered that exposure to nitrous fumes produced by blasting operations was a greater danger than that of possible chronic poisoning by carbon monoxide. The fumes of NO_2 are intensely irritating to the air passages and lungs, and the repeated inhalation of very small quantities would produce and maintain a chronic catarrhal condition, which would aggravate and accelerate the harmful effect of dust. As lighting torches were made up of blasting gelatine (a highly undesirable practice), it was advisable to limit the amount of NO_2 given off by torches.

The problem of extracting dust from mine air was also investigated by the Committee appointed to report on the ventilation of dead ends in 1924, but, although a certain amount of success was obtained, the experiments were not brought to a final conclusion.

This brings us up to date, and it seems as if only greater attention to detail, and possibly various minor changes, can effect any appreciable improvement in conditions without radically altering our present system.

If preliminary investigations made along the lines recently suggested by Dr. Haldane with regard to dust dilution tend to support his hypothesis, it may be found possible to carry out practical tests on a working scale which if successful would lead to the complete elimination of miners' phthisis.

SUMMARY OF TESTS FOR DUST (BEFORE AND AFTER BLASTING) PRESENT IN THE AIR OF WAITING PLACES OF THE SHAFTS OF CERTAIN MINES OF THE WITWATERSRAND TAKEN 1914-1915 (MINERS' PHTHISIS PREVENTION COMMITTEE)

[Dust: mg. per c.m. = milligrams of dust (mineral) per cubic metre of air. Before blasting = Prior to shots being heard. After blasting = From time first shots heard up to the hoisting away of last cage load of employees.]

Mine	Average period occupied by sampling	Number of persons hoisted during sampling period				Dust samples (mg. per c.m.)			
		Upcast shaft		Downcast shaft		Upcast shafts		Downcast shafts	
		Whites	Natives	Whites	Natives	Before blasting	After blasting	Before blasting	After blasting
All	1 hr. 35 mins.	1,301	14,941	1,654	22,206	2.8	10.4	3.5	4.9

This table clearly shows the large number of persons who were hoisted in upcast shafts during blasting at this time, and the big increase in dust concentration to which they were exposed. In 1917 this was prohibited [see Regulation 158 (5)].

THE USE OF WATER FOR ALLAYING DUST

The use of water was recognised as the most efficacious method of allaying dust produced by the various mining operations. The best methods of applying it effectively were only arrived at after years of experience and innumerable experiments.

Among the devices first used for dust allaying were sprays and atomisers. In 1903 experiments with the various types were carried out to test their relative efficiencies as dust allayers, and from the results of these tests Britten's atomiser was adjudged the best and awarded the Chamber of Mines first prize in the competition referred to previously.

At the outset water was not laid on to the working places; to operate the sprays and atomisers, drums were installed in the working place, and water carried in to them. These drums were connected to the compressed-air pipe, from which the necessary pressure was obtained to force the water out of the drum through a hose pipe to operate the atomiser or spray, which in turn was directed on to the collar of the hole being drilled whilst the drill was operating, thus damping the dust as it came out of the hole.

Sprays and atomisers were believed to be effective in allaying most of the dust produced during drilling and shovelling operations, and by 1906 many of the mines were equipped with them. Regulations were eventually promulgated to enforce their use. These devices were never popular with the miner; the atomiser charged the atmosphere with water, and everything within its range became saturated with water, including the miner's clothes; moreover in many cases the water was not clean, and the atomisers became choked and ceased to function. At their best, although allaying a considerable proportion of the dust formed, they did not prevent the very fine and most dangerous dust getting into the atmosphere. Gradually they were replaced by water jets, and ultimately (when water under pressure was available in abundance) by the hose pipe, sprays being retained only in such places as vertical shafts, and over ore boxes and ore passes.

Allaying Dust in Development Ends

The first attempt to allay dust produced by blasting in the development ends was to place an atomiser about 70 feet from the face and put it into operation when the charge was lit up; the smoke and fumes from the blast passing through the atomised water were to a certain extent deprived of their dust content; this, however, had no effect on the broken rock and did not clear the end of the drive of smoke. To overcome this defect the water blast was devised and introduced on an experimental scale in 1907, and gradually became common practice throughout the Witwatersrand, its use being made compulsory by Regulation in 1911. The water blast is a simple device consisting of a single nozzle connected to both a water and compressed air supply by means of which a mixture of air and water is projected along the drive to the face, wetting down the broken rock and displacing the gases produced by blasting operations.

Installing Pipe Lines for Water Supply

By 1906 many of the mines were using dust-allaying appliances for certain classes of work, and, as previously explained, the water supply to operate the various appliances had to be carried by hand into the working place: a very unsatisfactory practice and not conducive to obtaining the best results, specially in places difficult of access such as raises. The mines realised the necessity of a better water supply and commenced to lay water pipes into the working places, obtaining water chiefly from underground sources, and by 1908 a large number of the mines were so equipped, and Regulations were promulgated for the enforcement of this practice. The Mining Regulations Commission's report was issued in 1910, and at that time efforts were directed principally to allaying the dust produced by drilling and shovelling operations, it being assumed that these were the two chief sources of phthisis-producing dust.

The Medical Commission report of 1912 dispelled this illusion, and from then the attack on dust became more general, i.e. water had to be used freely to water down each working place after blasting operations before work commenced. The water service had to be further improved to supply the greater demand, and in most cases clean water was taken down the shafts supplying underground reservoirs made for the purpose, and distributed at suitable pressure to the working places, travelling ways and all other places when its use was considered necessary.

The introduction of an adequate water supply was the key to the solution of dust elimination. By the abundant use of water the dust is not only allayed, but washed down into the drains and sumps, from where it is either bailed or pumped out of the mine.

Water Feed Rock Drills

The " Water Leyner " rock drill was first introduced into the mines as far back as 1902. The principle of this machine as a dust allayer was accepted as correct at the time and its maker was awarded the Chamber of Mines second prize. The conservativeness of the miner, the poor class of material of which hollow drill steel was then made, and the lack of a satisfactory water supply delayed its successful introduction. In 1913 the " Water Leyner " drill and the Atlas drill, both passing water down the drill steel, were introduced on a number of the mines, and were very welcome from a health point of view. As time went on, reciprocating machines, both in stoping and development, were gradually eliminated by the water-fed machines, which apparently cut down dust production considerably.

At the end of 1916 a drilling machine known as the " dry " jackhammer was used; it worked with a hollow jumper, but exhaust air and not water passed down it. If a plentiful supply of water was turned into the hole by means of a jet, the dust results were at first considered satisfactory, but it was afterwards found that the air passing down the steel ejected considerable quantities of dust on escaping into the atmosphere. This led to experiments being carried out in 1919 with " wet " jackhammers, i.e. " axial water feed machines ", and some of the mines changed over to these " wet jacks " in 1920, and gradually they replaced the " dry " type. The advent of the " Kotze " konimeter revealed the fact that internal water-feed machines produced extremely fine dust of the most injurious nature which had hitherto passed unnoticed. This defect was to a certain extent overcome in 1922 by re-designing the rock drill machines, fitting them with dustless pistons and later by the introduction of release ports into the front head of the machines. The former reduced the amount of air escaping from the cylinder to the chuck cavity, and the latter allowed most of the escaped air to pass out of the chuck cavity instead of passing through the axial hole in the drill steel. To reduce the amount of air passing down the steel, Regulations were promulgated prohibiting the use of short pistons in certain classes of work, enforcing the adoption of release ports, and requiring all machines to be tested by the Mines Department and approved before being passed for use underground. At present endeavours are being made to develop a satisfactory external water-feed machine, which will practically prevent any air passing through the steel, the sludging being done by water only.

Other Sources of Dust

(*a*) *Dirty water supply.* — The machines atomise a certain amount of water, leaving the solid matter suspended in the air. The only check on this is to take samples of the water periodically and analyse them for solid matter (silica).

(*b*) *Blowing out drill holes.* — If this is done dry, it releases enormous quantities of dust, which should be washed out by water jets, avoiding the use of air if possible.

(*c*) *Blowing out sockets.* — Air should be avoided and water only used to wash them out.

Regulations

Government Notice 1278 of 1908: Amendment to Regulation 146

Recommendations of the Mining Regulations Commission:

(5) Every place where development work is carried on, and where the natural strata are not wet, and every dry and dusty stope shall be adequately supplied at all times with suitable clean water. Such supply shall be continuous and shall be sufficient for effectively damping the broken ground and for allaying the dust caused by drilling operations.

146. (ii) The ganger or miner in charge of workmen shall be responsible that the following provisions be observed:

(1) No person shall in the drilling of holes use any percussion machine drill, unless a water jet or spray or other means equally efficient is provided and used so as to prevent the escape into the air of dust caused by the drilling.

(2) No person shall in any part of a mine remove any broken rock or ground, if such rock or ground is in a dusty condition, until it has been effectively damped so as to prevent the escape of dust into the air during removal.

Act 12 of 1911

60. In development faces and in winzes a water blast or similar apparatus for laying dust after blasting must be used.

101. (1) No person shall in the drilling of holes use or cause or permit to be used any percussion machine drill unless a water jet or spray or other means equally efficient is provided and used, so as to prevent the formation of dust by drilling, and unless the floor, roof and sides of the working place, to a distance of at least 25 feet from the face, be kept constantly wet.

When hand drills are used for drilling dry holes, a swab shall be provided and used around the drill at the collar of the hole.

(2) No person shall in any part of the mine move any broken rock or ground if such rock or ground is in a dusty condition, unless and until it and the floor, roof and sides of the working place, to a distance of at least 25 feet, have been effectively wetted and kept wet, so as to prevent the escape of dust into the air.

Amendment Published on 31 October 1913

106. A ganger or miner who is the holder of a blasting certificate:

(32) Shall, at any mine included in the list of mines framed under section 2 of Act 19 of 1912, not enter nor allow any person to enter any end, raise, winze or other close place after blasting

within less than thirty minutes after putting the water blast in action, and then only if the air is free from dust, smoke and fumes perceptible by sight, smell or other senses.

(34) Shall in all development faces (except in the case of a winze being worked on single shift) immediately after lighting up, put into action the water blast, which he shall previously have tested. If as a result of such test, the water blast shall be found to be not in order, no blasting shall take place.

109. The following plans shall be kept in the office at every mine:

(2) (*b*) A plan showing all the water pipes with their dimensions as well as all tanks, reservoirs, fixed and continuous sprays, and other devices for allaying the dust.

158. (6) (*a*) Provide or cause to be provided an adequate and constant supply of water which is clean and odourless at every working place which is not naturally wet. Such supply shall be sufficient for effectively wetting the broken ground and for preventing the formation of dust caused by drilling operations. Such water shall be supplied in metal pipes not less than one inch in diameter, at a pressure of not less than 30 lbs./sq.in. at each working place, when all sprays and jets supplied from the same pipe are working. Such pipes shall reach to within 50 feet from the face and from there a sufficient length of hose shall be provided and used to bring the water up to the face.

(*b*) Cause the surface in all working places, travelling ways and shafts, which are not naturally wet, to be kept wet as far as practicable.

(*d*) Provide in shafts, which are not wet, ring sprays at suitable points to prevent dust being carried with the air current.

(*e*) Provide a water blast as near as practicable to all development faces (except winzes worked on single shift).

161. (9) Each shift boss shall at the end of the shift pay special attention to the requirements of Regulation 106 (32).

Amendment Published on 30 May 1917

Regulation 60 to be amended to read:

(2) Every drive, cross-cut, raise, incline shaft, and winze, and every working place in which there is no through ventilation current, shall be furnished, at a distance not exceeding 50 feet from the face, with a water blast, approved by the Inspector of Mines, which shall be continuously applied for at least thirty minutes after blasting, for the removal of dust and fumes, where the distance of such working place from the point at which there is connection with the general air current of the ventilating district exceeds 300 feet; an additional water blast shall be placed and used not more than 200 feet and not less than 100 feet from the water blast at the face.

Regulation 62:

(3) No person shall stope or be caused or permitted to stope above any drive or level where there is no through connection from the stope to the drive or level above, except by permission of the Inspector of Mines, and then only on the condition that the ventilation of such stope is adequate, that the number of persons working therein is limited, and that when machine drills are used, such machine drills are provided with axial water feed.

Regulation 101: section (1) to be amended to read:

(*a*) No person shall in the drilling of holes use or cause or permit to be used any percussion machine drill other than an axial water feed drill, unless a separate water hose, furnished in the case of dry holes, with a narrow pipe at least 24 inches long, for inserting in the hole when drilling, is provided for each machine and used, so as to prevent the formation of dust.

(*b*) In collaring by means of a percussion machine drill, other than an axial water feed drill, the narrow pipe shall be removed from the hose, and the water from the hose shall be turned directly on to the collar.

(*c*) No person shall use or cause or permit to be used any hand drill unless water is applied or a wet swab is used around the drill at the collar of the hole, so as to allay the dust.

(*d*) No person shall use or cause or permit to be used, for the purpose of rising or of boxholing, any machine drill other than one with axial water feed.

(*e*) No person shall commence or continue to drill any hole, or cause or permit such commencement or continuation of drilling, unless the floor, roof, sides and broken rock of the working place to a distance of at least 25 feet from such hole have been thoroughly wetted and kept wet.

(*f*) No person shall blow out or be caused or permitted to blow out any hole with compressed air unless he has applied sufficient water in case there is not already a sufficiency to prevent the formation of dust during the process of blowing out.

Section (3): No person shall in any part of a mine perform or be caused or permitted to perform work of any kind liable to create dust, unless and until the floor, roof and sides of the working place to a distance of at least 25 feet have been effectively wetted and kept wet, unless such working place is naturally sufficiently wet to render the formation of dust impossible.

Regulation 106 (34) to be amended to read as follows:

(34) Shall at every mine included in the list of mines framed under section 2 of Act 19 of 1912 only blast at the end of the shift, except for removing obstructions in ore passes or box holes or for the purpose of making the hanging safe, or for blasting misfired holes in development faces, and then only with the permission in each case of the manager, mine overseer or shift boss. Before blasting such obstructions in ore passes or boxholes or for making the hanging safe, the ganger shall wet the ground thoroughly within at least 25 feet of the obstruction. When blasting misfires he shall observe the precautions prescribed in Regulation 106 (33).

Regulation 143:

(*b*) Any defect in the mine water service or dust-allaying devices, or in any appliances provided for the health or safety of persons working underground, shall be recorded in the record book by the employee having knowledge of such defect immediately on coming off shift.

Regulation 158:

(6) (*a*) to be amended by the deletion of the words "which is not naturally wet" and the substitution therefore of the words "which is not sufficiently wet to make the formation of dust impossible";

(*b*) to be amended by the deletion of the words "as far as practicable" and the addition of the words "or regularly washed down".

To be amended by the addition of the following new subsection:

(*f*) Provide or cause to be provided at every ore bin, ore pass, or grizzley, unless exempted by the Inspector of Mines, a constant supply of clean water, which shall be applied during working hours at the openings of such ore bins, ore passes, and grizzleys, by means of efficient atomisers, which shall at all times be kept in good working order.

Regulation 158 to be amended by addition of the following section:

(23). Cause any surface dump as the Inspector of Mines may direct to be sprayed with a sludge of black soil, or otherwise dealt with in a manner satisfactory to the Inspector, so as to prevent the dissemination of dust or sand from it.

Regulation 161 to be amended by the insertion of the following section:

(10) (*a*) All matters relating to the mines water supply, its quality, distribution and use.

(*b*) The condition of the necessary appliances for using water at each working place and elsewhere.

Government Notice 1571 of 26 November 1918

Regulation 158: section (10) to be amended by the addition of the following subsection:

(*g*) Provide and cause to be used in every crusher station and ore sampling room, appliances, such as suction fans, atomisers and sprays, which may be necessary for the effective prevention of dust arising from the operations conducted in such station or room.

Government Notice 1730 of 26 October 1921

Amendments to Mines and Works Regulations

101. (5) (*a*) No new type or make of machine drill may be used on the scheduled mines without the prior approval of the Government Mining Engineer, or may be continued in use unless that approval is ratified by him within one year, and after at least twenty (20) of the machine drills so previously approved have been in regular use on the scheduled mines to his knowledge for a period of six months.

(*b*) The Government Mining Engineer may prohibit the use of any type or make of machine drill in use on any scheduled mine. Such prohibition (etc.).

Government Notice 1863 of 16 November 1921

Regulation 102 is hereby amended as follows:

102. (3) At any mine the ganger or miner making the examination prescribed in sections (1) and (2) shall also *thoroughly wet* the roof, sides and floor, as well as the broken rock, before admitting to the working place the members of the gang, other than those required to assist him in making safe.

Government Notice 511 of 21 March 1923

Regulations 60 (2), 101 (1) (*a*), 101 (1) (*b*) and 161 (10) to be deleted and the following substituted therefor:

60. (2) Every tunnel and development end, such as a drive, cross-cut, raise, incline shaft or winze, shall be furnished *with a water blast* approved by the Inspector of Mines. Such water blast shall discharge within a distance of not more than 50 feet of the face being advanced, and shall be applied so as to effectively wet the face and broken rock for at least fifteen minutes immediately after blasting, and again for a further period of fifteen minutes *immediately prior to entry* by any person, provided that the Inspector of Mines may give written permission to the manager to vary these conditions on any mine or part therefor.

101. (1) (*a*) No person shall, in drilling a hole, use or cause or permit to be used any percussion machine drill using solid steel, *unless a water hose is provided for each machine*, and used so as to prevent the formation of dust. When drilling a dry hole the *water hose shall be furnished with a narrow pipe* at least 24 inches long, which shall be inserted in the hole. In collaring, except in the case of jackhammers in stopes, the full bore of the hose must be used for supplying water to collar.

101. (4) (*b*) No person shall, in drilling a hole, use or cause or permit to be used any axial water-feed drill, unless an adequate supply of water flows through the drill steel. In every tunnel and development end, such as a drive, crosscut, raise, incline shaft or winze, and in every stope included under Regulation 62 (3) no person shall, in drilling a hole, use or cause or permit to be used any axial water-feed drill, unless an additional water-hose is provided and the water from it turned directly on to the collar while collaring. No drill steel shall be used in any *axial water-feed drill*, *unless the diameter of the axial hole is at least one-quarter of an inch* throughout its whole length, when the diameter of the drill steel is one and one-eighth inch or over, and at least three-sixteenths of an inch, when the diameter is less than one and one-eighth inch.

161. (10) In any mine included in the list of mines framed under section 2 of Act 19 of 1912, the manager shall, when the total number of persons employed underground on any one shift exceeds one thousand persons, appoint one or more competent persons whose principal duty it shall be to examine and report to the manager on:

(*a*) All matters relating to the mine's water supply, its quality, distribution and use.

(*b*) The condition of the necessary appliances for using water at each working place and elsewhere.

On 4 July 1923 the following machines were prohibited:

(*a*) The short-piston Leyner drill, in all development work, except shafts and winzes, after 10 March 1924.

(*b*) The Model 21 Waugh Turbro drill (Standard) in all classes of work, after 10 January 1924.

Government Notice 2046 of 8 December 1923

Prohibiting the use of any machine drill used with either shell or cradle which passes or is designed to pass air through the drill steel with or without water in all development work except shafts and winzes, after 10 March 1924.

THE GENERAL QUESTION OF MINE VENTILATION AND AIR RENEWAL, INCLUDING REFERENCES TO THE HEAT AND HUMIDITY PROBLEMS

BY G. A. WATERMEYER, B.A. (C.G.H.), A.R.S.M., PROFESSOR OF MINING, UNIVERSITY OF THE WITWATERSRAND; AND J. P. REES, A.R.S.M., B.SC., D.I.C., A.M.I.M.E., A.I.M.M., DUST AND VENTILATION OFFICER, TRANSVAAL CHAMBER OF MINES

The ventilation of the mines of the Witwatersrand is now almost universally produced by means of fans. The fans may be placed at any suitable point either on the surface or underground. But, wherever placed, the purpose is to cause the air to enter the mine through a down-cast shaft or shafts, to pass through the working places, and to return to the surface through the returns and upcast shafts. The primary purpose is to ventilate the working places. These are naturally divided into two types, the development ends and the stopes. To facilitate the operations of mining, the reef containing the gold is cut up into blocks by driving tunnels, both on the level (" levels ") and at the inclination of the reef (" winzes "). The operations involved in cutting out the blocks of reef (or " development work "), therefore, precedes the actual mining of the reef (or " stoping "). And as a general rule the fresh air is first directed to the development work and is afterward directed through the stopes.

The downcast shafts are generally used for lowering and raising men, material and rock, and for carrying compressed air and water pipes, as well as electrical cables. The timber framework of the shafts is kept wet by means of water sprays and in addition water often appears in the shafts from other sources. Hence the shafts are wet, and the air picks up a large amount of moisture during its passage into the mines and is kept correspondingly cool.

The air may pass in series through two or three shafts if the workings are at great depth, and then, towards the bottom of the mine, the air splits and travels out to the working places.

The velocity of the air in the splits is much less than in the shafts, and it is exposed to a much greater area of rock. Hence its temperature tends to rise rapidly towards the natural temperature of the rock. The rate of increase in temperature, however, is reduced to some extent by the evaporation of water and by the fact that the smaller the difference in temperature between the air and the rock, the slower is the rate of heat flow from the rock. Although most of the deep mines are very dry naturally, the floor of the levels leading to the stopes is wetted by water dripping out of the cars in which the broken reef is carried from the stopes to the shafts. The evaporation of this moisture tends to cool the air and so increase the heat flow from the surrounding rock. The result is that the wet bulb temperature rises as the air approaches the stopes.

In the development ends the workers are crowded together in a confined space (the " end "), whilst in the stopes they are more dispersed. Hence the need for large volumes of air is more vital in the development ends than in the stopes, and special attention is paid to the ventilation of the former. In 1923 a Committee was appointed jointly by the Government Mining Engineer and the Transvaal Chamber of Mines to consider methods of ventilating dead ends, particularly with the object of reducing the dust during drilling time to a minimum. This Committee recommended that development ends should be ventilated generally with at least 800 cubic feet of air per minute blown on to the working face by fans, or blowers delivering through large diameter pipes carried sufficiently near the face to produce a perceptible current of air there. As in some cases the mine air was not found to be sufficiently clean for this purpose, it was further recommended that in such cases a separate compressed-air jet delivering a minimum of 100 cubic feet of free air per minute be used. The air travels into the end through galvanised piping from 12 to 30 inches in diameter hung from the side of the drive; after ventilating the end the air travels out along the drive. In some cases, however, the air travels into the end along the drive and is sucked out through ventilation piping. But, by whichever system may be used, fresh air is supplied to the workers; the heat given off from the freshly exposed rock, from the workers and from their lamps is removed; and any dust that has escaped the water used to allay it is diluted and swept away. The length of tunnel that must be ventilated in this way is usually about 500 feet, and seven workers are engaged in the end with two machine drills.

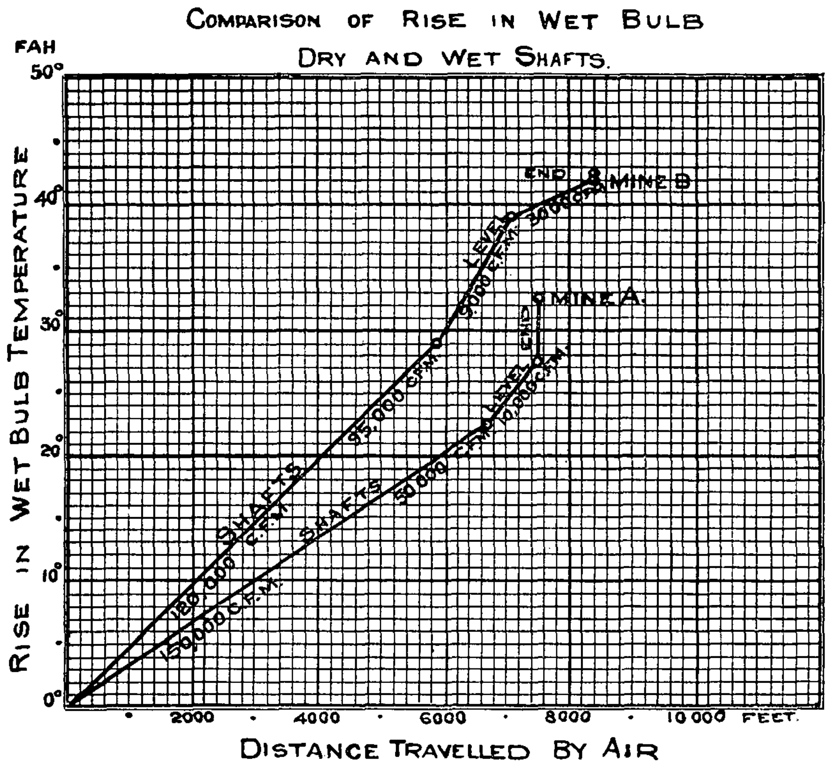
The workers engaged in shovelling the broken rock and in other duties may raise the total number of persons in the level to about two dozen. In the larger tunnels the length may run into several thousands of feet and the number of persons in the drive be doubled. The quantity of air circulated varies according to the circumstances, from 800 cubic feet per minute to 4,000 or 5,000 cubic feet per minute.

The development ends are generally situated in the lowest part of the mine and the stopes are then at a higher elevation. The ventilation is almost invariably arranged to pass up from the lower workings to those at a higher level, so as to take advantage of the natural tendency of heated air to rise from a lower level to a higher. The air, therefore, passes from the development ends to the stopes, though often the stopes are ventilated by air brought directly from the shafts. The air in its passage through the workings approaches saturation point. As it travels up the stopes, it continues for a time to be heated by contact with the warmer rock and to pick up more moisture from the artificially wetted surfaces. But, after a time, the air begins to cool by expansion and contact with cooler rock, so that in the higher stopes and in the return airways moisture begins to condense out. This is apt to produce a fog or mist. Mist may also be produced where warm air meets and mixes with cooler air, or in the neighbourhood of working compressed air machines. The air finally travels out through old workings and shafts to the surface. Where necessary, special ventilation shafts have been sunk at considerable cost to facilitate the return of the air to the surface.

In the stopes the air performs the same duties as in the development ends. Behind the working face in a stope there may, however, exist a very large open area, through which the air passes at a very low velocity. Small boosters of the Venturi type may then be employed to increase the rate of movement of the air along the face, or bratticing may be used to direct the air on to the workers.

The Village Deep mine has now reached a depth of 7,640 feet below surface, and is the deepest mine in the world. Some of the neighbouring mines are only a little less deep than this. At these great depths, the problem of supplying air sufficiently cool for work to be carried on efficiently has called for special attention. Air in passing down a shaft is compressed by the weight of the air above it. The work done produces heat which would under adiabatic conditions raise the temperature of the air 5½° F. for every 1,000 feet of depth. This heating effect is independent of the volume and cannot be reduced by the circulation of larger volumes of air. It so happens that on the Witwatersrand the rate at which the temperature of the rock rises from the surface downwards is almost the same, being about 5° F. per 1,000 feet in depth. This temperature gradient is extraordinarily slight and has been the decisive factor in permitting mining operations to be carried on to such great depths with copious use of water to allay the dust. For the evaporation of water reduces the temperature of the air far below that of the rock at the bottom of the intake shafts. This difference in temperature between the rock and the air sets up a flow of heat from the rock to the air which raises the temperature of the wet bulb to such a degree that it becomes difficult for the workers to get rid of their body heat produced during work. Although the evaporation of the water cools the air, the worker could not in any case receive any direct benefit, since the evaporation does not reduce the wet bulb temperature on which the ability of the body to get rid of its heat by sweating primarily depends. From the point of view of providing cool conditions, the use of water underground is therefore almost entirely objectionable. The flow of heat from the rock to the air can be stopped by the circulation of a sufficiently large volume of air which cools the rock for such a distance round the airway that the heat flow is negligible. For technical reasons it is difficult to produce a sufficient volume to effect this purpose even in shafts, and after the air has split it is quite impossible. Nevertheless experience has shown that by the circulation of large volumes of air the flow of heat from the rock can be diminished, and the conditions in the working places improved, not only because the wet bulb temperature is lower, but also because the cooling power of the air is increased by the increased rate of movement of the air.

Although normally the intake shafts of the Witwatersrand are wet, some of the shafts recently sunk are lined with concrete and cement, and equipped with steel and are in consequence comparatively dry. The graph on page 176 illustrates the wet bulb conditions in two development ends in different mines. In the case of Mine " A " the shafts through which the air passes are comparatively dry and in the case of Mine " B " are very wet. In both cases the shafts are vertical and the volumes passing are not widely different. The end at Mine " A " is 800 feet deeper than the end in Mine " B ". In spite of this greater depth the wet bulb temperature in the Mine " A " end is much lower than that



in Mine " B ", mainly owing to the smaller rise of wet bulb temperature in the downcast shafts. A big rise in the wet bulb temperature takes place in the Mine " A " end owing to the water used there and the comparative dryness of the downcast air. This graph shows clearly the adverse effect of the evaporation of water underground on the wet bulb temperature. The actual wet bulb temperatures in the ends were:

Mine " A "	79° F.
Mine " B "	88° F.

The cooling power of the air as registered by the wet katathermometer was, with two Leyner type machine drills [1] working:

	Millicalories per sq. cm. per second
Mine " A "	14
Mine " B "	7

[1] These machines each exhaust about 120 cubic feet of free air per minute.

In all the deep mines, in addition to providing as large a volume of air as is technically and economically possible to produce cool conditions, special attention is paid to the health of the workers, but this subject is dealt with elsewhere.

From this account it will be clear that the ventilation provides fresh air to the workers, ensures as far as possible cool working conditions, and with the help of water, keeps down the dust content of the air. After blasting (which only takes place once in the twenty-four hours) special conditions arise which are met by the prohibition of anyone entering the working places until sufficient time has elapsed for the smoke, fumes and dust to be swept away.

In order to ventilate the mines, very large fans have been installed. For instance, at the Government Gold Mining Areas the fan which ventilates the mine is capable of handling 900,000 cubic feet per minute at a water gauge of 7 inches. The fan is 30 feet in diameter and driven by a tandem compound engine developing 1,500 horse power. At the present time this is the largest mine fan in the world. On other mines are fans nearly as large. Mention might also be made of the propeller fan, which has proved particularly suitable for certain purposes. This is a recent innovation and is made up of one or more aeroplane propellers on a common shaft.

By means of these fans sufficient air is circulated to ensure that the quantity per person never falls below 30 cubic feet per minute. Indeed, although a very large personnel is employed underground, there is usually about 60 cubic feet per person per minute in circulation.

A REVIEW OF THE HISTORY OF SILICOSIS ON THE WITWATERSRAND GOLDFIELDS [1]

BY L. G. IRVINE, M.A., M.D., C.M., B.SC. (PUB. H.) (EDIN.), CHAIRMAN, MINERS' PHTHISIS MEDICAL BUREAU; A. MAVROGORDATO, M.A. (OXON), M.R.C.S. (ENG.), L.R.C.P. (LOND.), FELLOW IN INDUSTRIAL HYGIENE, SOUTH AFRICAN INSTITUTE FOR MEDICAL RESEARCH; AND HANS PIROW, D.SC., D.I.C. (LOND.), M.I.M.M., GOVERNMENT MINING ENGINEER.

THE GOLD-BEARING AREA OF THE WITWATERSRAND

Wherever mining operations are carried on on a large scale in silicious rock of "phthisis-producing" type, the menace of silicosis begins to appear so soon as the mining population has become a settled population, and especially is this the case where machine drills have been in extensive use.

That is the common experience, and that has been our experience in South Africa.

The prominence which the problem of miners' phthisis has assumed in this country has been due to the magnitude of the gold-mining industry, to the large number of miners whom it employs, and to its unique concentration upon a single large and continuous gold-bearing area. The problem has thus been at once larger and more sharply concentrated than in other countries, and the deaths and suffering caused by the disease have been more clearly apparent.

The gold-bearing area of the Witwatersrand extends for some thirty miles on either side of Johannesburg, the outcrop running roughly east and west, with the reef dipping to the south. The reef is a quartz conglomerate in a country rock of quartzite. Analyses published in 1916 in the *General Report* of the Miners' Phthisis Prevention Committee give the composition of the original ore, and of dust found in mine air. They show that the components of both are silica, silicates and pyrites. Dr. J. McCrae informs us that the probable order of the amount of free silica in the original ore is 75 to 80 per cent., but that in the dust, according to the published sample, it might be as low as 35 per cent. So far as the silicosis problem is concerned, it is only the very finest dust which counts, since only the minutest particles can be taken up by

[1] The writers are greatly indebted to Mr. F. G. A. Roberts, Technical Adviser to the Chamber of Mines, and to Mr. A. E. Payne, General Manager, Van Ryn Deep, Ltd., for valuable suggestions which have been incorporated in this paper.

" phagocytosis " into the lungs. Dr. McCrae, in his brief but classical paper on " The Ash of Silicotic Lungs " published some sixteen years agó, found that the mineral particles present in the lungs of miners who had died of silicosis were practically all under 5 microns, and 70 per cent. were under 1 micron in size.

Subdivisions of this Review

The history of silicosis on the Witwatersrand falls naturally into four periods:

(1) *The initial period of gold mining on the Rand, from 1886 to 1899,* that is, from the date of the first discovery of the reef until the outbreak of the South African War. One may fairly call this period, so far as local conditions are concerned, a period of ignorance of the dangers of silicosis.

(2) *The period of first realisation of the menace of silicosis and of tentative preventive measures, from 1901 to 1910.*

(3) *The period of the introduction of a legal system of compensation for the disease, and of the trial of more systematic preventive measures, from 1911 to 1916.*

(4) And, finally, what one may call: *The period of the " present-day " system of fully systematised measures of prevention, detection, and compensation, from 1916 to the present time.*

Our object in the following pages is to trace briefly the parallel and inter-related development of occupational conditions, of local knowledge of the disease, its types and its incidence, of the general legal attitude towards the problem, and of the general preventive measures which have been adopted.

I. — The Initial Period of Mining on the Rand from 1886 to 1889

This period was one of a large number of small " outcrop " mines. When gold was first discovered on the Witwatersrand in 1886, the deposit was regarded as consisting of auriferous gravels which had become solidified in parts.

Even when it was found that the gold was contained in an inter-bedded conglomerate, most engineers were sceptical about the real value of the discovery, as past experience had shown that the mineral contents of such conglomerates were so erratic and patchy as to preclude large scale workings. The true significance of the discovery was only realised many years later.

The eventual growth of the industry was never foreseen, with the result that the original lay-out of the mines proved unsuitable for subsequent deep level working. Some ten years after the first discovery, deep boreholes intersected the reef at depths of 3,000 feet, and led to the sinking of the first "deep level" shafts in 1898. During the first five years, mining on the Rand was largely confined to work in the oxidised zone which extended to a depth of from 60 to 300 feet. A considerable portion of the workings was open-cast, and, even when underground methods were resorted to, the ore was found to be comparatively soft and friable. It can, therefore, safely be said that the miners were exposed to little, if any, injurious dust during those days. Drilling was done by hand until about 1892, when large and heavy reciprocating machines, mounted on bars and driven by compressed air, were introduced in development ends.

From the beginning the mines have been worked by gangs of native labourers under the close personal direction of miners of European stock.

The European miners at that time were almost exclusively overseas men attracted to the Rand by high wages and bringing with them experience gained in other mining fields. To a large extent they came from Cornwall, where the population had been inured for centuries to mining conditions. The mining methods employed were crude, the development ends, which had been started by "hammer boys", were small and tortuous, following the reef exposure. No provision for mechanical ventilation was made, even when the workings reached depths of several hundred feet and when machine drills had been introduced in them.

When, however, the oxidised zone had been passed through, mining operations caused an excessive amount of highly silicious dust to be disseminated throughout the workings. In development ends, "cut" and "round" were blasted on the same shift, resulting in the miner with his assistants returning to the face through clouds of smoke and dust. Not realising the danger of exposure to this dust, neither the authorities nor the employees made any efforts to avoid exposure to it. Blasting took place at all hours, the miners, who were on contract and earned good wages, remaining underground until they had taken out their round or completed the blasting in their stopes. The sanitary conditions were equally unsatisfactory. No latrines were provided, and pollution of the working places was common practice. The living conditions on the surface were no better. Even when the tents and shacks, which served as shelter during the first few years, had been replaced by wood and iron and brick houses, living conditions were those of a typical mining camp. The water supply, which for many years was precarious, at times threatened to fail altogether; fuel was expensive; and for a number of years ox-wagon transport had to be relied upon for bringing the bare necessities of life from Kimberley, over three hundred miles of bare veld. It is, therefore, not at all surprising that the foundations of the industry, laid under such trying conditions, should have been found unsuitable for the subsequent deep level exploitation.

One may fairly say that locally this period was one of practical ignorance of the menace of silicosis, although towards the end of the period, when some years had elapsed after the introduction of rockdrills, it became known that a proportion of the miners were becoming affected with disease of the lungs.

At the close of the period in 1899, there were 100 mines working, hoisting about 8 million tons per year. White employees numbered about 12,000, coloured employees nearly 100,000. The number of underground employees at this time is not recorded. About 2,000 rockdrills were in commission, all of the " dry " reciprocating type. The average stoping depth was about 800 feet. The maximum depth reached at this time was 3,400 feet.

II. — Period of First Realisation of the Menace of Silicosis and of Tentative Preventive Measures, 1901 to 1910

The awakening came when work was generally resumed on the Witwatersrand after the cessation of the South African War. It was then found that a large number of rockdrill miners who had previously been working on the Rand had died during the war period, or within a short time after resuming work in the mines.

In the *Report of the Government Mining Engineer (Transvaal) for the six months ending December 1901*, it was stated that of 1,377 machinemen employed before the war, 225 were known to have died between October 1899 and January 1902. These numbers would give an average annual death rate of 73 per 1,000. Facts such as these arrested the attention of the Government, the mining community and the general public, and in December 1902 the first (Transvaal) " Miners' Phthisis Commission " was appointed by Lord Milner " to enquire into and report on the disease commonly known as miners' phthisis ". This body, usually referred to as the "Milner Commission", issued its Report in 1903.

THE MILNER COMMISSION, 1902-1903

This Report forms the first landmark in our local knowledge of the disease. An attempt was made by the Commissioners to procure a medical examination of all working miners, but the returns were incomplete, partly because many of the miners were reluctant to submit themselves to examination. However, 1,201 miners were examined; of these 15.4 per cent. were found to be affected by miners' phthisis and another 7.3 per cent. were suspected cases. Including the latter, the prevalence of the disease would thus appear to have been about 23 per cent., but this figure is probably too low. A very significant feature brought out in the Report is that, in spite of the number of newcomers required to replace the losses amongst rockdrill miners, the vast majority of the miners employed at this time still consisted of miners who had had their first and often a lengthy experience of mining overseas. Miners born overseas made up well over 90 per cent. of the total. The limited evidence adduced indicated that mining work in the Transvaal, especially rockdrill work, was more dangerous than similar work elsewhere, but the Commissioners were justified in the conclusion that previous mining work in other countries had contributed to some extent to the prevalence of the disease. In 1904 the *Report on the Health of Cornish Miners*, by Dr. J. S. Haldane and Messrs. Martin and Thomas, put the position from the Cornish standpoint. This Report contains the statement that the great increase which had occurred in recent years in the death rate amongst miners living in Cornwall had been due to the deaths of men who had worked rockdrills, and that " the great majority of these deaths are attributable to the effects of rockdrill work in the Transvaal or elsewhere abroad ", although " a considerable number are attributable to work in Cornwall ". One may believe that there was truth on both sides and the exceptional danger of rockdrill work in the Transvaal remained common ground.

The Transvaal Commission found that, although cases of miners' phthisis were chiefly noticeable amongst rockdrill miners, they were also found amongst miners who had never worked with rockdrills. The men affected were mostly younger men, their average age being thirty-five and a half years. The limited evidence available showed that the rockdrill miners affected by the disease, who had worked only in the Transvaal, had had an average underground service of under six years. The *Report on the Health of Cornish Miners* gives an average duration of service of 4.7 years for affected men who had worked only in the Transvaal.

The very dusty conditions then prevalent underground are shown by several gravimetric measurements published in the Commission's Report, which, although few in number, may be taken as fairly reflecting the position then existing. One may quote the following—the figures are milligrams per cubic metre of air: stopes, 14 and 32; raise, 164; face of drive, 192 and 424. The mines were very dusty, and they were also largely dry.

The sanitary conditions underground, especially in disused workings, were found to be frankly bad; no attempt at organised sanitation was made.

Type of Silicosis Prevalent at this Period

The type of silicosis produced by these conditions is described in a statement by the Transvaal Medical Society which the Commission published in full, and is illustrated also by the somewhat crude but nevertheless effective coloured plates attached to the Report. It was the "classical" type of silicosis, with heavy bulky lungs characterised by an excessive development of pathological fibrosis, which tended to obscure evidence of coincident infection, except as a rule in the terminal stage. Death occurred in either of two ways, by cardiac failure with dropsy and without emaciation or obvious signs of tuberculosis, or, on the other hand, by a rapid terminal tuberculosis. Local medical opinion at the time was that the majority of cases were "non-tubercular", although a "mixed fibroid and tubercular type" was recognised. Probably this conclusion was partly due to the migratory character of the early mining population; many of the deaths which occurred did so after the return of the men to their homes overseas. But Dr. J. S. Haldane and his colleagues, speaking from experience in Cornwall, were emphatic that, in the majority of cases, including returned Transvaal miners, death was due to tubercle. Obvious tuberculosis was however typically a late phenomenon. One should probably relate the "classical" type of silicosis seen in these years, in which the changes due to dust immensely predominated over obvious changes due to infection, mainly to the kind of occupational conditions existing, but to some extent also to the kind of miner who was exposed to these conditions. The miners of that time were drawn almost exclusively from older mining centres which had long been industrialised and they had presumably therefore a relatively high inherited or acquired immunity to tuberculosis. They were for the most part men of initially robust physique.

Preventive Measures Adopted

Certain general recommendations regarding dust prevention, particularly in development work, and regarding ventilation and underground sanitation, and the provision of " change houses " for miners, were made by the Commission. A phrase in the Report of the Transvaal Medical Society—" *dry mining must as far as practicable become wet mining* "—reflected contemporary opinion and indicated the main direction in which measures of dust prevention on the Rand have proceeded ever since.

As a result of the Commission's work certain Regulations were issued in 1904 and 1905, under Act No. 54 of 1903.

These Regulations required that sprays or jets were to be used with machine drills, that broken ground was to be damped in development places, and that blasting operations should be arranged so as to avoid exposure to dust, and they prohibited return to working places after blasting until the air was clear. Efficient ventilation was to be provided.

But, unfortunately, no effective means were prescribed to ensure that these measures should be actually carried out, and the inborn conservatism of the miners, who disliked innovations in traditional ways of working, did not help matters. A considerable improvement was unquestionably effected in the directions indicated, but it was not sufficiently thorough to produce very substantial results. The idea remained that the main cause of the trouble was rockdrilling and that rockdrill miners were almost the only sufferers. The very dangerous conditions produced by the widespread dissemination of blasting dust received quite inadequate attention.

Occupational Conditions in this Period

The period 1901 to 1910 brought many " deep level " mines to the producing stage and the main changes in occupational conditions and mining methods during this period may be summarised as due to the greater depth and wider extension of the mine workings. The restricted area of many of the old " outcrop " mines combined with the fact that the dip of the reef was found to be considerably less in the deeper workings gave rise to a number of amalgamations of the smaller properties. Thus, whilst the tonnage hoisted and the gold produced rose steadily year by year, the actual number of mines on the Witwatersrand decreased. The average grade of the ore mined fell, and it became obvious that only those properties which could work on a large scale and held a large area for exploitation could survive for any length of time. These amalgamations obviously had a marked effect on mining methods and also caused a great change in the mine ventilation. Boundaries between the small properties were stoped out, and even where this did not occur holings became increasingly frequent. As a result, the course of the natural ventilation currents underwent many changes. Although the result in individual cases was distinctly beneficial, yet the lasting effect of the many holings was definitely detrimental to a lay-out providing for efficient ventilation of all the working places. This heritage in the course of years became more serious, and at a later stage, when mechanical ventilation had to be resorted to, it was found that radical changes, though desirable, could not be effected except at a prohibitive cost.

The evidence of various dust samples taken during this period shows that dust conditions remained in general of much the same order as regards dangerous dust as they had been in 1903.

Much credit is due to the Chemical Metallurgical and Mining Society of South Africa for the active attention devoted by its members to the subject of miners' phthisis during these years, which served a very valuable educative purpose. The discussions which centred round papers contributed particularly by Drs. Macaulay and Irvine, Dr. James Moir and Mr. W. Cullen did much to extend the knowledge of the mining community regarding the nature and danger of miners' phthisis, to elucidate the nature of accidents from " gassing " underground, and to direct attention to the question of mine ventilation.

The Mining Regulations Commission, 1907-1910

In 1907 a second Commission was appointed by the Government of the Transvaal—the " Mining Regulations Commission ". Its primary reference was to revise and suggest amendments to the Mining Regulations; and in this connection its members devoted much attention to miners' phthisis, to the question of " gassing " accidents in the mines, and to mine ventilation and sanitation. Medical evidence was led by Drs. Macaulay and Irvine on the " Conditions affecting the Health of Underground Workers ", and by Dr. G. A. Turner on the " Health of Mine Natives ". From the evidence submitted by the former it was found that the local mortality from phthisis during the years 1905 to 1907 had been approximately six times higher amongst underground workers than amongst other adult males on the Rand, but that the age period of maximum mortality fell somewhat later amongst the former, a feature which is recognised to be characteristic of " dust-phthisis ".

The final Report of the Mining Regulations Commission was not issued until 1910. A revised code of Mining Regulations, based upon its recommendations was promulgated in 1911, and instituted many improvements, which began to take effect from the latter date and which represent the inauguration of the next period.

The chief of these improvements were the introduction of qualitative tests of ventilation, to supplement the quantitative requirements of older Regulations, and power was given to require the introduction of mechanical appliances where the natural ventilation current was insufficient. As before, the use of a water jet or spray was required in machine drilling; and the responsibility of the manager to maintain an adequate and constant supply of clean water for use for these appliances and for damping down working faces and broken rock in ends and stopes, was tightened up. An important innovation was the requirement that a *" water blast or other suitable appliance " should be used in development ends to control dust from blasting*, and further provision was made for the protection of all persons in the mine from fumes and dust, and for the prompt hauling of coloured labourers to the surface at the end of the shift. The ventilation of winzes was specially provided for. Responsibility was placed on the sectional officials to secure the proper observance of preventive regulations. Finally, back-to-back living rooms on the surface were prohibited, and underground sanitary organisation received detailed attention.

The result was that the use of water for dust-laying underground became from this time much more general. The following figures show very strikingly the effect of these measures, and the conditions existing at this time of transition.

DUST IN MILLIGRAMS PER CUBIC METRE

(Samples taken at the Bottom of an Upcast Shaft in a Deep-level Mine)

	Sept. 1911: No sprays	April 1912: Sprays	Sept. 1912: Sprays
9 to 10 a.m.	280	32	3.3
11.30 a.m. to 12.30 p.m.	130	21	0.2
2 to 3 p.m.	80	39	2.1
4.15 to 5.15 p.m.	100	14	17.1

An important event which is to be referred to this period was the opening in November 1911 of the Miners' Phthisis Sanatorium at Springkell, the capital expenditure being provided by the Transvaal Chamber of Mines. This institution has ever since filled a most valuable purpose in providing free special medical treatment of cases of miners' phthisis.

At the close of this period in 1910, the number of mines working was eighty-four. These mines were hoisting nearly 27,000,000 tons of rock per year. The white underground employees numbered over 10,000; coloured underground employees over 120,000. The average stoping depth was 1,100 feet; the maximum depth reached at this time was 4,500 feet. Some 5,500 rockdrills were in commission: all or nearly all were of the " dry " reciprocating type.

III. — Period of Introduction of a Legal System of Compensation for Silicosis and of Trial of More Systematic Preventive Measures, 1911 to 1916

The new Code of Mining Regulations published in 1911, which introduced this period, has already been noted. The important matter of hours of work underground was also dealt with at this time under Act No. 12 of 1911, which limited work at the face to eight hours per day and forty-eight hours per week. This had the effect in practice of an eight-and-a-half-hour day from bank to bank [1]. The same year, 1911, witnessed also the first institution of a legal system of compensation for the disease. In the first session of the Union Parliament the Minister of Mines introduced a preliminary measure—the " Miners' Phthisis Allowances Act of 1911 "—to provide temporary relief for men affected, pending more extensive legislation.

A " Miners' Phthisis Board " was appointed to administer the Act, and this body, with various subsequent changes in composition, still performs this very important office.

At the same time (June 1911) a further Miners' Phthisis Commission was appointed, composed entirely of medical men and hence known as the " Miners' Phthisis (Medical) Commission ", " to enquire into the prevalence of miners' phthisis and tuberculosis on mines within the Union ", and to advise from the medical point of view on provisions for legal measures for compensation.

[1] The practice since 1918 has been to work eight and a quarter hours bank to bank on weekdays and seven and a quarter hours on Saturdays.

THE MINERS' PHTHISIS (MEDICAL) COMMISSION, 1911-1912

The Report of the " Medical " Commission, issued in February 1912, forms the second landmark in the medical history of silicosis in South Africa.

The actual examinations made were more complete than in 1903, but they did not cover the whole of the underground employees. A general clinical examination was made of 3,136 working miners, supplemented by a special examination of 326 men, in which radiography was for the first time applied to the examination of cases on a fairly extensive scale by Dr. A. H. Watt, at the Simmer and Jack Hospital.

By these means the prevalence of definite cases of the disease amongst the working miners examined was found to be about 26 per cent., with an additional 5.5 per cent. of doubtful cases. This figure is somewhat higher than that found in 1903. It gives no reason, however, to conclude that the situation had retrogressed, since the earlier date; it probably merely reflects the result of a more extensive investigation.

Machine drillers were still the occupational group most affected, and the Commissioners concluded that, regarding this group, the statement made in the Report of the Transvaal Medical Society in 1903, that " the working efficiency of a rockdrill miner working under present conditions would be impaired or even exhausted after seven to nine years' work ", still held good. Although other occupational groups showed much lower attack rates, no class of underground workers, including the supervisory staff, was free from serious risk of attack. The importance of the factor of tuberculosis in the course of the disease was fully recognised in the Report, in which it is stated that " in at least the great majority of cases tuberculous infection becomes towards the end superimposed upon the pre-existing silicosis ". The Report adds that " there has been undoubtedly since 1902-1903 a distinctive alteration in the predominant clinical type of the disease ".

The average duration of underground service in the whole class showing the first definite physical signs of the disease was 8.2 years, and the average age of those so affected 35.5 years: for machine-men, with South African experience only, the average duration of service was 6.1 years.

It was suggested that, for purposes of compensation, cases should be divided into three stages: early, intermediate and advanced, and that for the two latter a pension or annuity should be payable.

Pure tuberculosis was found to be comparatively rare amongst miners at work, and while the Commissioners were agreed that " miners' phthisis " was definitely an " occupational " or " industrial " disease, they were also agreed that pure tuberculosis could not be so regarded.

The Miners' Phthisis Act of 1912

The Report of the Medical Commission was the basis of the " Miners' Phthisis Act of 1912 ", which introduced for the first time a system of legalised compensation for the disease.

This Act has proved to be only the first of a long series of subsequent amending and consolidating measures, each of which has been marked in general by an increase in the amount of the awards payable to fresh cases, and by additional provision for surviving beneficiaries under former Acts, or for the dependants of deceased miners. It is unnecessary to trace the development of this complicated mass of legislation in detail, but some reference may be made to certain of its general aspects.

The system adopted in the Act of 1912 is of interest principally because it marked a definite policy, which has since been superseded.

Two " stages " of the disease were recognised—a " first " applying to " a miner who shows definite physical signs of miners' phthisis and whose capacity for underground work is thereby not seriously or permanentlym ipaired ", and a " second " applying to " a miner who has contracted silicosis in a marked degree and whose physical capacity for underground work is thereby seriously and permanently impaired ".

Sums (whose total amount was limited) were paid for each stage in instalments. The miners contributed 2½ per cent. of their wages towards the liabilities for these payments in respect of new cases, and this system was continued until 1919. No award was payable to cases of pure tuberculosis.

A panel of medical examiners was appointed to carry out the medical examinations of European claimants and to certify as to their eligibility for an award. Natives suspected to be suffering from miners' phthisis were examined and certified by the Mines' Medical Inspector. The former system led to a considerable lack of uniformity in the standards of certification adopted. Increasing use was made by some examiners of radiography to supplement clinical examination, but this was far from general. Only those miners who made voluntary application for benefits were examined, and no periodical examination of all working miners was provided for. Although a medical examination of new recruits was authorised, this also suffered from a very considerable lack of uniformity.

Incidence of Silicosis in this Period

The number of awards of benefit granted in these years to working and retired miners was very considerable and is shown in the accompanying table:

ORIGINAL AWARDS TO MINERS FOR SILICOSIS MADE BY THE MINERS' PHTHISIS BOARD FROM 1912 TO 1916

Year	First stage	Second stage	Total
1912-1913	698	1,632	2,330
1913-1914	1,087	993	2,080
1914-1915	912	367	1,279
1915-1916	540	243	783
1912-1916	3,237	3,235	6,472

At the outset of the period there existed a large number of "accumulated" cases amongst working and retired miners. If we make an allowance of 3,000 as the approximate number of these, the figures would suggest that some 800 to 900 new cases were arising in each year during this period. That this approximate estimate is probably fairly near the truth is further suggested by the fact that, after nearly 6,500 working or retired miners had thus been compensated during these four years and debarred from further underground work, the Bureau detected over 900 cases of "primary" and "secondary" stage silicosis amongst miners who were actually at work during 1916-1917. These facts indicate that the incidence of the disease at this period was decidedly worse than it has since become. It must be remembered that even the new cases arising during these years would on the average represent the cumulative effect of occupational conditions the beginning of which dated back to some eight or ten years previously.

The lack of uniformity in the medical standards of certification employed by different members of the "panel" of examiners, and of systematic means for the detection of fresh cases as they arose, resulted in a general feeling that the system adopted in 1912 was unsatisfactory. In 1916, accordingly, a Parliamentary Select Committee was appointed to reconsider the position. The Report of this body recommended the adoption of an altogether different policy.

One may note here that contributions to the local literature of the subject were made during this period by Dr. J. McCrae (1913), by Dr. W. Watkins Pitchford (1914 and 1915), and by Drs. Watt, Irvine, Pratt Johnson and Steuart (1916).

Progress of Preventive Work from 1912 to 1916

Following on the Report of the "Medical" Commission the Minister in February 1912 had appointed a "Miners' Phthisis Prevention Committee" under the chairmanship of Sir Robert Kotze. This body was an authoritative and representative one, composed of Government mine inspectors, mining engineers and mine managers representing the industry, working miners, medical men and other technical advisers. It was appointed "to enquire into and report upon methods for the prevention of miners' phthisis, and to advise on the introduction of a systematic and uniform policy". The composition of the Committee afforded an opportunity for continued close co-operation in preventive work between the Department of Mines and the industry. It may fairly be said that "the formation of this Committee marks the initiation of the first really energetic steps to stamp out the disease". Two interim Reports were issued by the Committee in 1912 and 1913, in which urgently needed steps were indicated. In 1913 a large number of Regulations were promulgated incorporating these recommendations. In addition to amplifying and more accurately defining existing Regulations, additional provisions were introduced. In 1913 it was required that *an adequate supply of water should be provided throughout each mine by means of a system of pipes.* This cardinal requirement led to much greater efficiency and uniformity in the provision of water for use with sprays and jets and water-blasts, and for wetting working-places and broken ground, and hence to a more extended and adequate application of these methods. In 1914 a further Regulation *prohibited the blasting of "cut" and "round" separately on one shift*, except by special permission of the Inspector of Mines. The practice so restricted had long been recognised as a peculiarly harmful and dangerous one.

Regular determinations of the dust in mine air had been begun by the Consolidated Goldfields Group in 1911. The first systematic dust survey of *all* the mines was conducted by the Prevention Committee in 1913-1914. The general average result was 5.4 milligrams per cubic metre of air, the highest results being found in raises, drives and at orebins. These figures are much below the values of earlier observations, but still very considerably higher than recent results. In 1914 the Chamber of Mines established a special Dust Sampling Committee under the charge of Mr. James Boyd, and systematic surveys of workings in all mines have been carried out since that date by that Committee. In addition, since 1916 each mine has conducted its own dust surveys. The body of evidence so collected is now enormous, and provides useful guidance regarding dust conditions.

The method of dust sampling first employed was the gravimetric sugar-tube method, used with screening in order to exclude very large particles. In 1916 Sir Robert Kotze introduced a dust-sampling instrument which he named the " Konimeter ". In that device a measured quantity of the air to be examined is made to impinge on an adhesive-coated microscopic slide, and the number of particles in the " spot " so produced is subsequently counted under the microscope.

For long there was controversy as to the relative merits of the sugar tube and the konimeter. It may be agreed that no one method of sampling the air for dust is satisfactory in all respects. The phthisis-producing properties of dust particles depend upon their size and upon their quality. Sugar tube or gravimetric methods do not discriminate size, and konimetric or optical methods do not discriminate quality.

The konimeter has two great advantages for routine work: a low konimeter count means safe conditions, while this does not necessarily apply to a low sugar-tube return. Further, the konimeter is handy, and can be used in observing rapidly changing dust conditions. The methods of konimeter work are at present being investigated with a view to standardisation by a Joint Committee of the Department of Mines and the Chamber of Mines. There can be no doubt of the value of this instrument, when properly used, for giving approximately accurate relative results which will serve as a sufficient guide for most practical purposes.

Occupational Conditions during this Period

During the years 1911 to 1916 mining methods on the Witwatersrand underwent a number of changes notably as regards the lay-out of the mines, the ventilation systems and the type of machine-drill employed.

The greater depth to which the workings had penetrated, as well as the larger area over which they had extended necessitated larger shafts and development ends. It was also realised that in order to handle the increased tonnages and to improve ventilation, the drives and cross-cuts had to be laid out on as straight lines as possible, although the great bulk of the underground tramming was still being done by hand.

A more radical change took place in the ventilation systems of mines. In 1908-1909 the first large mechanical fans were installed on some mines and during the next decade all the deeper mines found it necessary to follow suit in order to clear the workings of fumes from blasting. The importance of ventilating currents in reducing the residual fine dust in the mine air had not yet been fully realised, when mechanical ventilation was installed.

An important change in the type of machine-drill came about when the reciprocating drill was superseded by the hammer type of drill. The latter was smaller and lighter, and thus more easily handled and its drilling speed was also considerably greater. The holes drilled by these machines were smaller in diameter but not only did the new machine drill more holes per shift than the old one, but in striking a larger number of blows per inch drilled, it also pounded the rock very much finer than did the reciprocating machine, and thus produced a greater proportion of fine dust. In addition, some types of hammer drill exhausted air only through the drill steel, with the result that excessive quantities of microscopic particles of dust were disseminated in the mine air, in spite of the fact that water was applied externally to remove the sludge from the drill hole. This new position had to be met by investigation into the use of air, or air and water, or water only with rock-drilling machines.

The General Position in 1916

One may note here an important development which had been going on during this period and the later years of the previous one. In 1903 over 90 per cent. of the miners employed on the Rand were men of overseas origin and the great majority of these had had previous mining experience elsewhere. But a steady increase had been proceeding since that time, particularly since 1907, in the number and proportion of miners of South African birth and training. It was noted by the Miners' Phthisis Medical Commission in 1911 that in that year, 35 per cent. of the miners examined were South African born, and that, although 65 per cent. were of overseas birth, only 19 per cent. of the whole number examined had had previous mining service elsewhere. To-day 73 per cent. of the working miners are of South African birth, and 91 per cent. of the whole body have had their experience of mining solely in South Africa. The position has therefore been completely reversed since 1903. The industry has become throughout a genuinely South African industry. The recruits of South African birth have been drawn mainly from the rural community. It may be suggested that the presumably lower acquired immunity to tuberculosis in a population of this origin, may have contributed, along with the progressive reduction of dust in mine air, to the greater and earlier relative prominence of the element of tuberculous infection in our local cases, which had already begun to be noticeable before 1916.

The number of mining companies at work in 1916 was fifty-five. They employed underground over 11,000 Europeans and over 155,000 coloured employees. The rock hoisted per year was 32,000,000 tons. During the period the number of rock-drills in commission had increased from 5,500 in 1910 to 9,500 in 1916, and 40 per cent. of the rock mined was broken by rock-drills. The average stoping depth was 1,600 feet; the maximum depth reached was 5,250 feet.

IV. — Period of the "Present Day" System of Fully Systematised Detection and Prevention

The year 1916 was a cardinal year in the history of silicosis on the Rand. It was marked by two new departures—the institution of the Miners' Phthisis Medical Bureau, and the publication of the *General Report* of the Miners' Phthisis Prevention Committee. From 1916, therefore, we may suitably date the period of the "present day" system of detection and prevention of silicosis on the Rand.

The Miners' Phthisis Act of 1916 and the Institution of the Medical Bureau

The Miners' Phthisis Act of 1916 was the outcome of the Report of a Parliamentary Select Committee which sat in that year.

This Act continued the previously existing system of limited awards for two "stages" of silicosis, but the amounts granted were increased in this year, and still further in the succeeding year. The two "stages" were now termed "primary" and "secondary". The interpretation given to the definition of the "primary" stage by the legal advisers of the Crown was that it should be held to include only such cases as showed some amount of disability; an interpretation in conformity with the general usage regarding cases of industrial "injury". The basis of compensation may have been temporarily somewhat affected by this decision.

A further step was taken by the inclusion under the Act of cases of pure tuberculosis when detected amongst miners actually at work. It was not conceded that pure tuberculosis is an occupational disease: the object was to remove from underground work cases of tuberculosis which were actual or potential sources of the communication of infection to others, and the award was granted to the affected miner simply in view of compulsory retirement from his occupation. The grant was originally made only to cases detected amongst miners at work during a period of one year from the date the system came into force. Later amending legislation, however, ultimately established the privilege of a miner to claim compensation for simple tuberculosis, provided that the condition is detected by the Bureau in a miner who is actually at work underground in a scheduled mine, or who has been so employed within not more that twelve months prior to the date on which the disease was detected.

Perhaps the most important innovation introduced by the Act of 1916 was the institution of the "Miners' Phthisis Medical Bureau"—as a central body of whole-time Government medical officials to conduct or control all medical examinations under the Act.

In the case of European miners the main functions of the Bureau have been:

(1) To conduct an "initial examination" of all new recruits for the industry;
(2) To conduct a "periodical examination" of each working European miner once every six months in order to secure the early detection of all cases of silicosis or tuberculosis which arise amongst the working miners;
(3) To conduct a "benefits examination" of all miners or ex-miners who claim compensation in respect of the presence or suspected presence of silicosis or tuberculosis, and
(4) To decide from the medical standpoint upon the claims of dependants of deceased beneficiaries.

In the case of native mine labourers, the "initial" and "periodical" examinations are conducted under Regulation by the mine medical officers acting as examiners under the Act. The Bureau, however, exercises general powers of supervision over these examinations and is directly reponsible for the examination and final disposal of all natives suspected by the mine medical officers to be suffering from silicosis or tuberculosis.

The first Chairman of the Medical Bureau was Dr. W. Watkins Pitchford, on whom the heavy work of the initial organisation of that institution fell. Dr. Watkins Pitchford continued to direct the activities of the Bureau for a period of ten years up to September 1926, when he was succeeded by the present Chairman (Dr. L. G. Irvine).

Subsequent Changes in the Principles of Legislation on Miners' Phthisis

Acts affecting minor changes in the system of compensation were passed in 1917 and 1918. Accumulating experience of the progressive character of most cases of silicosis gave support to the feeling that cases of silicosis should become eligible for compensation at the earliest detectable stage of that condition, irrespective of whether disability was present or not. It was hoped that, if this were done, the disease might be detected, and the men be given the opportunity of leaving underground work, while the condition was still non-progressive. This principle was therefore adopted in the Miners' Phthisis Act of 1919, which was the outcome of a further reconsideration of the problem by a third "Miners' Phthisis Commission" (1918) and by a Parliamentary Select Committee. Since the earliest stage of silicosis compensated under the previous Acts had been termed the "primary" stage, the somewhat anomalous expression "ante-primary" stage was introduced to designate the earlier condition which it was now intended to render compensatable. In this Act also simple tuberculosis was finally recognised, under the restrictions already mentioned, as a compensatable condition in miners. Judged from the preventive aspect, the wisdom of that decision is, we think, unquestionable. A further change of importance was the provision of a maintenance life pension for miners who had reached the "secondary" stage of grave incapacitation, with an allowance for their wives and children.

The " ante-primary " and " primary " stages were made compensatable by limited lump sum payments. Holders of a periodical certificate were entitled to remain eligible for a periodical examination provided that they presented themselves for examination at intervals not exceeding two years.

Minor amendments were effected in 1918 and 1924; a further Commission—the " De Villiers Commission "—re-examined the situation in 1921; and finally, in 1925, a new consolidating Act was passed—the " Miners' Phthisis Acts Consolidation Act of 1925 ". This measure aimed mainly at " levelling up " the awards granted to beneficiaries under the previous Acts to the scales of award instituted for new cases in 1919. The Act also required that medical officers appointed by mining companies to attend mine natives should be whole-time officers, power being reserved to the Minister to allow exemption in the case of small mines. This measure has tended to a more uniform and effective system of medical examination of natives for the purposes of the Act. Finally a " Medical Board of Appeal " was appointed with power to revise decisions of the Medical Bureau in respect of any examination at which the question of possible compensation was involved. This provision was made to meet the case of persons dissatisfied with the decisions of the Medical Bureau, and has added elasticity to the whole system. It cannot be said that complete satisfaction with the present system has been attained, and at present another Miners' Commission is once more reviewing the situation.

One may note here that further contributions to the literature of the subject have been made since 1916, particularly by Dr. A. Mavrogordato (1922 and 1926) and by Dr. W. Watkins Pitchford (1927).

The " General " and " Final " Reports of the Miners' Phthisis Prevention Committee, 1916 to 1919

The publication of the *General Report* of the Miners' Phthisis Prevention Committee in 1916 forms the second feature which makes that year a landmark in the local history of silicosis. This Report and the Committee's *Final Report* of 1919 contained a large number of further detailed recommendations aimed at the prevention of miners' phthisis. The work of that Committee was not, however, confined to the issue of general recommendations. Perhaps its most important work lay in the detailed survey of all mining operations which it accomplished and the formulation of a detailed policy of dust control for each of these, the careful investigation of actual appliances suggested or in use for dust prevention which it carried out, and the illustrations published of those appliances which appeared best to meet their purpose. The Chairman of the Committee, Sir Robert Kotze, was, throughout the period of its sittings, in close touch in these respects with the officers of his department and with the technical advisers of the industry. An amended code of Mining Regulations, issued in 1917, embodied the cumulative result of the Committee's work.

Perhaps the most important additional measure introduced in 1917 was the provision that *blasting should take place only once in twenty-four hours, at the end of the day shift.* Blasting the " cut " and "round " separately on the same shift was now totally prohibited. Other related provisions were that work and shifts should be so arranged as to avoid exposing persons to fumes and dust from blasting, and that the night shift should only enter the mine after the lapse of an interval fixed by the Inspector of Mines. For control of the dust generated in blasting only an approved water blast was permitted.

The Regulations relating to ventilation were amplified. It was required that a prescribed minimum quantity of air must be provided for every person employed underground, and that the air must be suitably " split ". Special requirements were made restricting back-stoping, and for the special ventilation of development ends. For machine drilling only a jet or a drill with axial water-feed was permitted.

Finally, it was provided that a special dust and ventilation officer should be appointed for each mine, and that regular dust determinations should be made.

In 1918 there followed Regulations enforcing dust prevention in crusher stations and assay rooms.

Subsequent to 1919 further investigations with effect in practice have been made by two Joint Committees appointed by the Department of Mines and the Chamber of Mines for special purposes —one on " Water Blasts and Ventilation " was appointed in 1921, and the second, on the " Ventilation of Development Ends " in 1923.

In 1921 a Regulation was promulgated giving the Government Mining Engineer control over the types and makes of machine drills which may be used on " phthisis " mines. Since then no new machine drill may be introduced without the prior approval of the

Government Mining Engineer, and a system of testing drills with regard to dust production has been established. The principal outcome of this provision has been that the *use of machine drills not provided with an axial water-feed has been prohibited since 1926.*

In 1916 the majority of rockdrills in commission were still of the "dry" reciprocating type. In 1918, 10,500 rockdrills were in use of which nearly half were of the hammer type, and 40 per cent. of these were "dry" drills. In 1928 the reciprocating type had practically disappeared, and 8,500 hammer drills, all of the "wet" type, were in commission.

To ensure observance of the Regulations inspections of the mines are being constantly made by the Government mining inspectors, who in many of their inspections aid their ordinary observation by taking dust samples with the konimeter. Control is also exercised by the industry itself through the Dust Sampling Committee of the Chamber of Mines, whose inspectors make routine sampling visits to the mines, as well as visits to obtain samples in connection with particular observations. The samples are taken either with the sugar tube or konimeter. They are examined at a laboratory maintained by the Chamber for that purpose, to which also the samples taken by the dust samplers on the individual mines are sent for examination and report.

Finally, the Minister in 1926 appointed a second Miners' Phthisis Prevention Committee, similar in constitution to the first, to carry on similar work.

Occupational Conditions since 1916 and the Present Position

The development of that portion of the Witwatersrand goldfields situated between Benoni and the village of Nigel and popularly known as the "Far East Rand", did much to change the ventilation systems on the Witwatersrand. The areas of individual mines on this portion of the Rand are considerably larger than were those of the older mines. The reasons for this fact may be briefly indicated as follows:

These areas were known to contain extensive unpayable blocks of ground, the reef lay at depth without outcrops to the surface except in the extreme North West and South East, the dip of the reef was small, and a large amount of virgin ground was rendered available under the mining leases system.

As a result very little, if any, natural ventilation could be hoped for, and the lay-out of the mines had therefore to be adapted to the requirements of mechanical ventilation. Again, efficient handling of the broken rock underground could only be obtained by means of mechanical haulages requiring large haulage-ways with the minimum of bends or constrictions, and thus also facilitating improved ventilation.

As a mining field the Witwatersrand to-day stands unequalled as regards the scale on which operations are carried on, the depth the workings have attained, the organisation involved, and the extent of the precautions taken to prevent miners' phthisis. Visible dust underground is as rare as it once was common, exposure to fumes from blasting if occurring at all is accidental, and sustained efforts are being made to provide improved ventilation.

The main difficulties encountered lie in the fact that the lay-out of many of the older mines is unsuitable and the necessary alterations could not be effected except at prohibitive cost. Although a great amount of attention is now paid to ventilation requirements in the original lay-out, the enormous expense of shaft sinking resulting from the great depth of the shafts and the hardness of the rock limit the area of the shafts very considerably. The danger of rock-bursts, the large unpayable areas which have to be driven through on certain mines, the close packing required for support, the narrow width at which stoping must be carried out in some mines in order to be payable, and the fact that the large ore reserves must be blocked out in advance are further factors which tend to limit the cross-sectional areas of these underground excavations, along which the main downcast current has to travel before reaching the actual working faces.

Again, these very working places are so scattered that extensive splitting of the air current is necessitated on most mines. A further complication arises from the fact that relatively few mines can be regarded as separate units as regards their ventilation systems. Holings into neighbouring mines are continually increasing, boundary pillars are being removed and the ventilation system of two or more mines must frequently be treated as one composite problem. On most mines the workings are interconnected to such an extent as to make the circulation of a main air current extremely difficult and costly. If the dust content of widely scattered stopes and development ends, in the latter of which most dust is created, is to be efficiently diluted, a good deal more ventilation will be required in such places, and on some mines the cost would be prohibitive.

At the present time the number of mines working on the Witwatersrand is forty-five but of these nine are small tribute companies working portions of mines which had previously been shut down.

The number of European miners employed is over 10,000 and of underground coloured employees over 147,000. The tonnage hoisted is over 36,000,000 tons per annum, practically all of which is broken by rock drills. The average stoping depth is 2,700 feet. The maximum depth attained is 7,638 feet (October 1929).

The Chief Factors in Preventive Policy since 1916 and their Results

Following the summary review outlined in the last Report of the Medical Bureau one may say that since 1916 four kinds of preventive methods have combined to influence the situation.

Two of these make up what one may call the "engineering methods" aimed directly against the production or dissemination of dust in mine air. One may perhaps conveniently distinguish these as:

(1) *"Dry" methods of prevention*, by which one means measures which do not directly depend upon the use of water. These are the measures, already described, to secure an adequate standard of ventilation both general and local, to regulate the methods and times of blasting, to secure the arrangement of shifts and the times and manner of hoisting so that there should be no unnecessary exposure of any person to dust and fumes, and measures of a similar character. The general tendency to think of the use of water as the all-important measure in dust prevention has perhaps tended to an under-estimation of the cardinal importance of the provisions just mentioned.

(2) *"Wet" methods of prevention*, by which one means measures which depend directly on the use of water to allay dust at its source, or to remove it from the air when formed. Every mining operation is now covered by meticulous regulations having this object, of which we have already mentioned the chief. When in 1916 the Miners' Phthisis Prevention Committee found that the adequate use of water suitably applied would reduce the amount of dust generated in drilling and blasting by 97 or 98 per cent. by weight, it appeared that the problem had been solved. It had only been solved *so far*. The further statement made by the Committee that water would lay the dangerous dust in equal proportion to the coarser harmless dust has since required, and in our opinion still requires, re-investigation.

There is no doubt that the combined operation of these two groups of preventive measures has effected an immense reduction in the quantity by weight of dust in mine air. One may in illustration quote the following results of the gravimetric observations made by the Dust Sampling Committee of the Chamber of Mines:

Year	1915	1917	1919	1921	1923	1925	1927
General average	4.9	3.8	2.4	1.6	1.3	0.9	1.2
Development	6.9	5.4	3.5	2.3	1.9	1.0	1.2
Stopes	3.4	2.9	1.9	1.2	0.9	0.7	0.9
Orebins	4.4	4.2	2.9	2.1	1.8	1.6	1.9
Total samples	1758	6188	7491	6695	4872	2399	2869
Percentage of samples above 5 milligrams	27.0	20.0	10.0	4.0	3.4	1.7	1.4

Figures represent milligrams per cubic metre of air.

The other classes of preventive measures one may call the " medical measures ".

Of these, two are of chief importance:

(3) The " *initial examination* " of recruits conducted or in respect of native labourers controlled by the Bureau. The object of this examination is to prevent the entry into the industry of persons suffering from respiratory diseases (including tuberculosis) or of persons who appear to be unduly liable to contract such diseases.

A very important result of the initial examination in the case of European miners has been the gradual introduction since 1916 into the general body of working miners of a group of men of specially selected physique, whom we call the " new Rand miners ", and who now number over 8,300, or 54 per cent., of the whole body.

In the case of the mine natives there are three medical examinations of recruits, a preliminary sifting in the recruiting area, a principal examination at the Witwatersrand Native Labour Association's depot in Johannesburg, and a supplementary examination by the mine medical officers.

(4) The " *periodical examination* ", similarly conducted or controlled by the Bureau, which aims at the detection of all cases of simple silicosis, tuberculosis with silicosis, or of simple tuberculosis, amongst the working miners and the mine natives. European miners actually in employment are examined by the Bureau every six months.

From the purely preventive aspect the most important consequence of the periodical examination is the permanent removal from underground work of persons found to be suffering from tuberculosis or tuberculosis with silicosis, who are thereby prevented from remaining as potential sources of dissemination of infection.

The number of cases of these conditions detected amongst European miners has fallen steadily during the past ten years and does not now constitute a serious menace.

The preventive aspect of the periodical examination is of more importance as it affects the native mine workers.

The periodical examination of native labourers is carried out, under the Act, by the mine medical officers, who are almost exclusively whole-time men and are an active, organised and progressive body. The system of examinations of natives on the mines is rather complicated.

Every native employee is weighed once in six weeks, and all who show more than a prescribed loss of weight are set aside for special medical examination; all natives with more than five years' service on any mine undergo a further special medical examination every three months, and all natives on leaving employment have to undergo a " final " medical examination. These are the prescribed examinations. In addition the medical officers examine the chests of all natives admitted to hospital for any cause. And finally the Chamber of Mines three years ago instituted an annual X-ray examination of long service natives. The whole system draws round the mine natives a serviceably close net of opportunities for detection of cases of silicosis and tuberculosis.

Suspected cases are sent to the Bureau for final examination and disposal.

The result of the examinations of mine natives discloses that simple tuberculosis and tuberculosis with silicosis taken together are decidedly more prevalent amongst them than amongst the European working miners. The reverse is true of simple silicosis.

Even so, when judged by European and American experience the attack rate for tuberculosis amongst mine natives is not alarming. But the actual number of cases detected annually is considerable, and, so far as underground conditions are concerned, it is from the mine native that the menace of tuberculous infection arises both in the production of cases of frank tuberculosis and in that of early infective silicosis amongst European and native employees alike. Hence the necessity of continuing the campaign to reduce all possible sources of tuberculous infection in the mining population to the fullest practicable extent.

One may add that three years ago a " Tuberculosis Research Committee ", representative of the Government and of the Chamber of Mines, was appointed to make a fresh investigation of the tuberculosis problem.

THE INCIDENCE OF SILICOSIS SINCE 1916-1917

What now has been the practical result of all these intensive efforts ?

It is only during the past twelve years—from 1917-1918 onward—that we have been able to obtain from the published Reports of the Medical Bureau accurate figures regarding the new cases of silicosis which have actually arisen year by year.

During the whole of that period of twelve years there have been detected by the Bureau at the periodical examination of working miners 4,362 cases of simple silicosis, 382 cases of tuberculosis with silicosis, and 409 cases of pure tuberculosis.

Reduced to average figures these numbers represent, in the case of simple silicosis alone, *an average annual* production of 363 cases, amongst a population of 13,600 working miners, or 2.66 per cent.

The actual incidence has, however, varied considerably from year to year. Let us attempt to follow its general course, and for convenience let us divide the whole period into four shorter periods, each of three years' duration.

For the years 1917 to 1920 the incidence averaged 3.5 per cent., but the returns for these years were inflated by the inclusion of a considerable number of " accumulated " cases of early silicosis, which became compensatable as " ante-primary stage " cases in 1919-1920.

Partly owing simply to the removal of these accumulated cases, there followed in the years 1920 to 1923 a drop in production to an average of 1.9 per cent.

The next three years, 1923 to 1926, witnessed on the other hand a well-marked rise to an average figure of 3.3 per cent., culminating in a maximum peak of 3.8 per cent. (490 cases) in 1925-1926, a figure precisely double the average rate for 1920 to 1923.

This marked increase naturally attracted much attention and aroused misgiving.

But, as was first publicly pointed out by Dr. A. Mavrogordato, it had quite an innocent explanation. It was not attributable to a worsening of hygienic or occupational conditions underground.

The greater part of it was due to the simple fact that the mining population had become more settled and was growing older—older, that is, in length of underground service. During that period, accordingly, there had been a steady increase in the number of miners with long periods of service behind them and with a *correspondingly greater liability to contract silicosis.* Everyone knows that, other things being equal, the longer a miner has worked underground the more liable he is to contract silicosis, and therefore the greater the number of miners with long service that are working the greater must be the number of cases of silicosis. That was one thing that was happening in these years. The remaining and lesser portion of the increase was attributable to a different cause. It was due to a temporary augmentation of the cases detected, occasioned by a further liberalisation in the standard of diagnosis of the earliest recognisable stage of silicosis, attained during these years by the Bureau, as the result mainly of improvements in X-ray technique, and of the consequent possibility of a more exact correlation between the radiographic, pathological and clinical signs presented in a large series of cases. A liberalisation of the standard of selection of this nature, however, only effects a material increase in the number of cases detected when it is being applied for the first time, and when, accordingly, two grades of the disease are being taken out at once. Once it has been applied all round to the whole body of working miners, the temporary increase disappears.

As the result of this investigation it was, therefore, possible to predict that this temporary increase, at least, would shortly disappear, and that the rise which it had occasioned would be succeeded by a fall. And the fall occurred in due course. In 1926-1927 the incidence of silicosis dropped back to 2.7 per cent.

But the further drop which has since occurred to a figure of 1.76 per cent. in 1928-1929 is even more satisfactory. It represents a genuine improvement *because it has been effected in the face of a continued increase in the number of older miners at work.*

When one makes allowance for the influence of that increase, one is able to state with entire confidence that the true production of silicosis, when measured *(as it can only be truly measured) by the respective attack-rates for the disease amongst the miners at work in each corresponding respective year of underground service*, shows a decided improvement upon the condition which obtained six years ago, before the intervening rise occurred.

The most striking evidence of improvement is seen in the returns for the specially selected body of men who have entered the industry since 1916, and whom we have termed the " new Rand miners ". These men now number over 8,300 and are increasing year by year. Now whereas in the period from 1920 to 1923 the attack rate for silicosis amongst all miners who were working in their tenth year of service was 5 per cent., amongst the "new Rand miners" working in their tenth year of service in 1928-1929 it was only 1.3 per cent. Part of this effect is certainly due to the better stamp of man of which the "new Rand miners" are composed. But if we allow an equal share to that factor this result is still remarkable. One cannot indeed anticipate that rates of this low order will continue when the "new Rand miners" enter the later periods of service, but there is no reason to suppose that they will even then reach the relatively high figures which the older miners have hitherto shown.

The duration of underground service amongst those miners who became silicotic during the past year was over twelve years. Of the 270 cases detected during that year, 90 per cent. had begun work prior to August 1916—prior, that is, to the beginning of the "present-day" period. One must remember, as we have said, that the cases of silicosis which arise in any one year are the cumulative result of the conditions obtaining during the previous ten or twelve years.

All of this is reassuring. But one must add a definite word of caution. Although we have turned a big corner in the matter of silicosis, one does not anticipate that the actual number of cases detected will show any significant further decrease in the immediate future. For, although the "new Rand miners" with their relatively lower attack rates are becoming more numerous and the older miners fewer, nevertheless, the older miners who remain, and there are still well over 5,000 of them, are every year getting still older in years of service, *and therefore more liable to contract silicosis.* The one factor will probably for some time balance the other, and, as a consequence one does not anticipate much, if any, actual decrease in the number of cases which will arise for a good many years to come.

Some Outstanding Problems

Reference may be made here to the recent strong move on the Witwatersrand towards reconsideration of the methods of combating miners' phthisis underground. The principal line which those concerned in that movement have taken has been to urge that "wet" methods of dust allaying should be replaced where possible by "dry" methods, and that, where "wet" methods are still found necessary, the amount of water used should be as small as possible. Two main factors have encouraged the movement. On the one hand, there has been growing realisation of the discomfort, inefficiency, and even danger to life from heat stroke, arising from high temperatures combined with high humidities in deep and insufficiently ventilated mines. On the other, a strong medical opinion, in which the two medical joint authors of this paper share, has established itself to the effect that the rapidity with which many of our cases of " simple " silicosis pass to the " infective " type is in part connected with the increased facility of infection induced by the dampness and high humidity underground. There are, however, many problems to be solved before practical effect can be given to such a policy. While the comparative ineffectiveness of water in sprays or on wetted surfaces in removing from the air those very fine particles of dust, under 5 microns in diameter, with which we are concerned, is now well known, and was demonstrated in the case of the water blast, formerly looked upon as very effective, by the Witwatersrand Joint Committee on the Ventilation of Development Ends in 1923, it remains to be shown that ventilation can be increased or other means found to enable the sprays or wet surfaces to be wholly or partially given up without detriment. It has also to be shown that methods can be found which will in practice allow reduction in the very effective results of the use of water in checking the rise of fine dust from holes being drilled or from broken rock or ore being shovelled.

Another point which has to be considered is whether or not, when all that is possible has been done in cutting out the use of water for dust allaying, the amount of water naturally percolating into the mine shafts and working places or inevitably used for dust allaying will not still be sufficient to give high relative humidity in the mine air. It has to be remembered that less than 20 gallons of water will give a relative humidity of over 90 per cent. to 100,000 cubic feet of air at 87° Fahr.

Another type of preventive measure calls for consideration. It has been noticed for many years that in certain industries wherein silicosis production might be expected the disease has either been absent or of very low prevalence and has occurred very late in the working life of the employees. It has been suggested that this happy state of affairs may be related to the presence in the air, together with silica, of some particles that serve as an antidote. This hypothesis is particularly associated with the name of Dr. John Scott Haldane, and he called the attention of the Witwatersrand to its possibilities in 1918 and again in 1929. It is desirable to locate these industries and to secure data as to the actual amount of dust of silica to which their employees are exposed and to confirm the reputed absence of silicosis by examinations of employees and some method of " follow-up " similar to that obtaining on these fields.

The whole matter is bristling with fascinating problems for both the scientific investigator and the practical engineer.

Conclusion

In conclusion a word may be said about the possibilities of future developments on these fields.

It would appear that although the life of a number of the existing mines is limited there are others whose production is likely to continue for twenty and more years, and in addition there are further areas of virgin ground which presumably will give rise to the opening up of new mines. It is, therefore, evident that the fight against miners' phthisis is likely to continue for many years to come unless a satisfactory solution to our present problems can be found. Judging by our experience of the past, it is practically certain that our mining methods will also undergo considerable changes in the future. The tendency exists throughout the Witwatersrand mines to adopt mechanical means for handling and transport of the broken rock and it is conceivable that this fact may have become an important factor in the prevention of miners' phthisis if, with the advance of engineering methods, a large proportion of the manual labour can be eliminated and thereby human exposure to phthisis-producing dust can be lessened.

AETIOLOGY OF SILICOSIS (DUST-PHTHISIS)

BY A. MAVROGORDATO, M.A. (OXON), M.R.C.S. (ENG.), L.R.C.P. (LOND.),
FELLOW IN INDUSTRIAL HYGIENE, SOUTH AFRICAN INSTITUTE FOR MEDICAL RESEARCH

While thanking the Conference for the honour done me, I remember that I am before an audience many of whom have travelled some six thousand miles to be present and are intimately acquainted with the subject. This is not the occasion to approach the matter in the spirit of a post-graduate lecturer.

The lungs are used to inhaling dust and used to getting rid of it, and one may perhaps recognise exposure to four main types of dust:

(1) Dust that is harmless.
(2) Dust that is usually harmless but may contribute to the mischief when inhaled in association with a harmful dust.
(3) Dust that is usually harmless and may have actual prophylactic value when inhaled in association with a harmful dust.
(4) Dust that is harmful.

When dealing with silicosis one is not concerned with dusts that are harmful by virtue of being irritant; such dusts make their mischief after a different fashion. Our concern is with what is now pretty generally known as "phthisis-producing dust". For a dust to be phthisis-producing it must possess certain qualities some of which may be enumerated as follows: it must be capable of overcoming the lung's physiological ability to rid itself of dust and of getting itself arrested, and of getting itself so arrested for a considerable time. As dust particles do not multiply of themselves, it must be relatively indestructible by tissues and tissue-juices.

Since the initial means of arrest is by phagocytosis, it must be of a size to lend itself to this process; that is to say, it must be about the size of the common pathogenic micro-organisms.

It must be too inert to bring about the ready destruction of the cells that take it up, and too inert to provoke a free production of the cells that take it up or to provoke the production of any considerable exudation. Dusts that when inhaled provoke a moist condition of the lungs associated with expectoration are not readily retained for long by normal lungs.

Dusts that lend themselves to arrest and the production of a dust-phthisis do not readily destroy the cells that take them up, and the laden cells tend to aggregate into what Koch called pseudo-tubercles. Here, then, is one means of arrest. A suspension of such dust injected intra-venously will be retained among other situations in the lungs, and will there set up a similar reaction to that which it sets up when inhaled. It is the exception for injected suspensions of particulate matter to behave in this fashion, and the procedure affords one means of testing the phthisis-producing qualities of a dust. Pseudo-tubercle production is another feature. For some years I have been interested in the fact that in tolerably pigmented lungs one may find areas clear to the naked eye, but surrounding an intensely black spot several millimetres across: much larger than the ordinary pseudo-tubercle. I have examined many of these spots in microscopic preparations, and usually they are aggregates of dust-laden cells surrounding a minute lymphoid nodule. I saw two such cases recently with Dr. Sutherland Strachan, and he tells me that he attaches considerable importance to the part played by such nodules in the arrest and distribution of dust. As to why these nodules should hold up some dusts rather than others is a further point. I am disposed to relate it to the prolonged preservation of the dust-laden cells, and attribute this preservation to the dust being slightly soluble. The pseudo-tubercle formation also suggests a chemical factor entailing a measure of solubility. There is a *vires acquirit eundo* quality about a dust-phthisis, and one suspects certain dusts of possessing the property of provoking an allergic response in the tissues which implies the need for their being to some degree soluble.

The dust that possesses these qualities and dominates the dust-phthisis of industry is dust of free silica, SiO_2.

Clinical dust-phthisis is a protean disease and, as with other diseases, in considering its ætiology one must consider together the agent, the subject, and the conditions of exposure.

Let us start with the agent. You cannot have tuberculosis without the tubercle bacillus, and you cannot have a dust-phthisis without a phthisis-producing dust. So far so good; but the dust or agent may be " pure " or " adulterated ". In practice the agent is always more or less adulterated and, nowadays, the adulterant interests us perhaps more than the primary agent. The adulterant may be inanimate, that is to say other dust, or animate, that is to say micro-organisms. When I first came in real contact with the subject of dust-phthisis it was as assistant to Dr. J. S. Haldane, and I found my chief's attention particularly focussed on this question of the inanimate adulterant. This was getting on for twenty years ago, but in a fox-hunt Dr. Haldane would be found in front of the fox. The question was this: why, given the presence of a phthisis-producing dust, did those exposed seem on occasions to escape the disease, and why did the disease vary so widely both in incidence and severity ? Obvious considerations such as intensity and duration of exposure did not cover all the facts. Colliers, for instance, might be exposed to phthisis-producing dust when drifting and shaft-sinking, yet they were held to be particularly fortunate in avoiding respiratory diseases in general and dust-phthisis in particular. In certain American mining districts the miners ought to have been suffering from the disease, but, as far as the evidence went, they were not doing so. It was possible that SiO_2 might vary in its nature or that certain other dusts when inhaled with SiO_2 might serve as an antidote. As Sir William Garforth used to say, where you find nettles there you find docks. It was on such an hypothesis that experiments were performed comparing the influence on animals of exposure to dust of free silica alone and to an equal dose of dust of free silica but with coal dust added [1]. Different series of these experiments were performed over many years, some in Dr. Haldane's private laboratory at Oxford, some at St. Thomas's Hospital in London, and some at the South African Institute for Medical Research, Johannesburg. The results may be summarised by stating that coal inhaled simultaneously with silica did help silica out of the lung, but that previous invasion by coal did not appreciably hinder the settlement of silica, nor did a subsequent invasion of coal bring out settled silica. Coal dust is not the only dust that has this property; Professor E. L. Collis has pointed out that, in the manufacture of fire-bricks, the presence or absence of certain " clays " seems to decide the prevalence or absence of silicosis among the workers, although the exposure to silica dust is practically the same in amount and

[1] *Journal of Hygiene*, Vol. XVII, 1918, p. 439. *Publications of South African Institute for Medical Research*, No. XV, 1922, p. 15, and No. XIX, 1926, p. 19.

under similar conditions in each case. Of late years instances of this kind have accumulated; I shall confine myself to mentioning one of them.

By the courtesy of Dr. L. P. Stokes, in response to an enquiry, Dr. Orenstein was informed that on the Kolar Gold Field they had met with only one case of silicosis in a European who had not worked in a phthisis-producing industry elsewhere: this man had worked underground for thirty-eight years. Dr. Stokes adds: "We have not found primary fibrosis in any Indian cases." Pulmonary tuberculosis is increasing throughout India, and a latent tubercle infection is frequently made active by underground work.

Systematical medical examination of European employees, including an X-ray examination, is the rule on the Kolar Gold Field, so one may assume that silicosis is not arising. The mines are quartz mines, but until one knows the total silica and free silica in their rock one must beware of attaching too much importance to freedom from silicosis on this field.

Just as the presence of certain dusts seems to interfere with the ability of silica dust to settle in the lungs, so too the effective occupation of the lungs by silica dust seems to interfere with the ability of the lungs to rid themselves of dusts that do not settle in normal lungs. Does a phthisis-producing dust set up an allergic state? The analyses of the dust-content of the lungs of those who have died with a dust-phthisis always show the presence of dusts other than the incriminated dust, while in the case of our own sufferers the lungs are often as black as a collier's, even though the subject gave up mining years before his death. I have shown that, in our subjects, the "black" or pigment is mostly carbon from the soot provided by the acetylene lamps used underground[1]. In experimental animals that have received heavy doses of silica dust by inhalation and then been left to live out their lives where they were exposed to smoke, then carbon is to be found in the silica-stricken areas of their lungs, though not elsewhere. I do not believe for a moment that this carbon did any harm, but I do suggest that, in the presence of a dust known to be phthisis-producing, all dust should be regarded as potentially harmful unless known to be helpful. In this context one may refer to the collections of coal dust to be found in the lungs of old colliers who have worked for many years at "hard-headings".

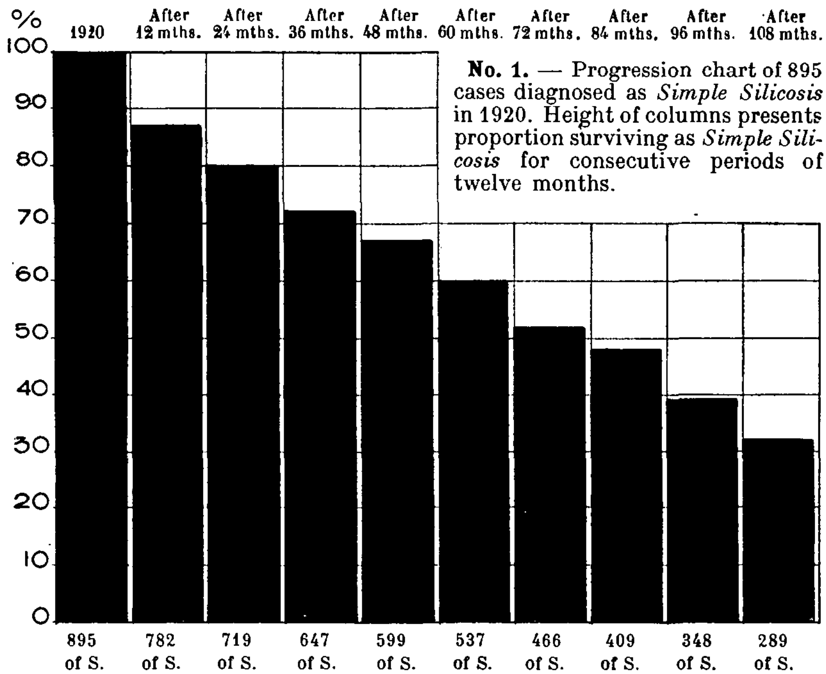
The question of the inanimate adulterant can be left here with

[1] *Publications of South African Institute for Medical Research*, No. XV, p. 54.

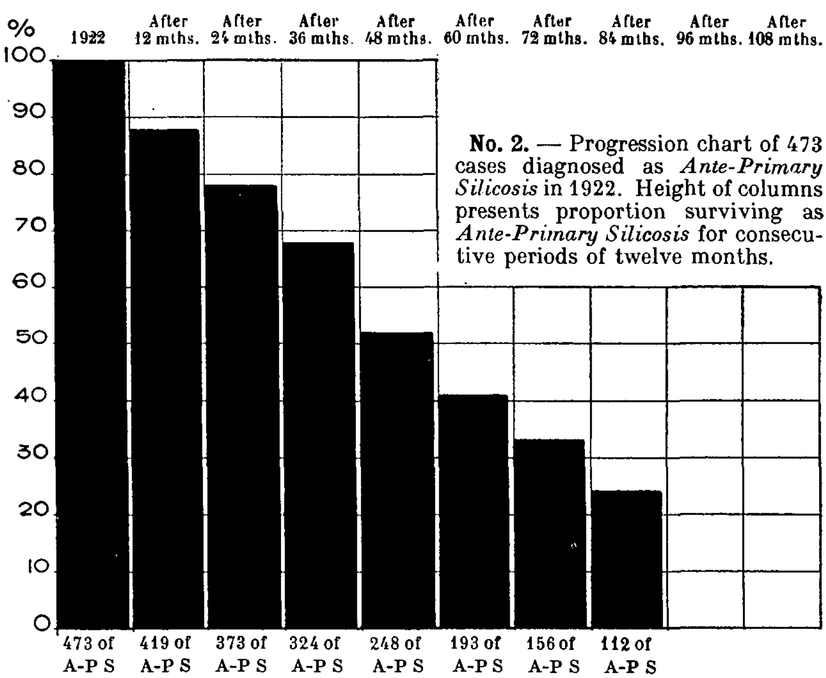
the comment that it suggests two lines of research; one of them very important. In the case of industries not associated with a serious incidence of dust-phthisis, although exposure to phthisis-producing dust appears adequate for its production, then the specific antidote must be sought in case it is present, perhaps in small quantities, as an inanimate adulterant. In the case of phthisis-producing industries associated with an incidence of simple dust-phthisis beyond that which experience would lead one to expect, one must beware an inanimate adulterant in addition to other possibilities.

Let us turn to animate adulterants or micro-organisms. The distinction between "simple" and "infective" silicosis or dust-phthisis in a phthisis-producing industry is as important as the distinction "clean" and "dirty" cases in surgery. In this disease disability and death are always associated with a greater or lesser degree of the infective element, but in some industries and in districts with a high prevalence of dust-phthisis the disease persists for a long time in the clinically simple stage and progresses but slowly, while in other districts and industries the infective factor comes into evidence early, and often with the result that many cases show rapid progression even after the subject has given up a phthisis-producing occupation. Unfortunately, on the Witwatersrand we are confronted by the type of the disease in which the infective factor is of great importance. (See accompanying graphs by the Miners' Phthisis Medical Bureau, Johannesburg, 1920 and 1922, pages 214 and 215.)

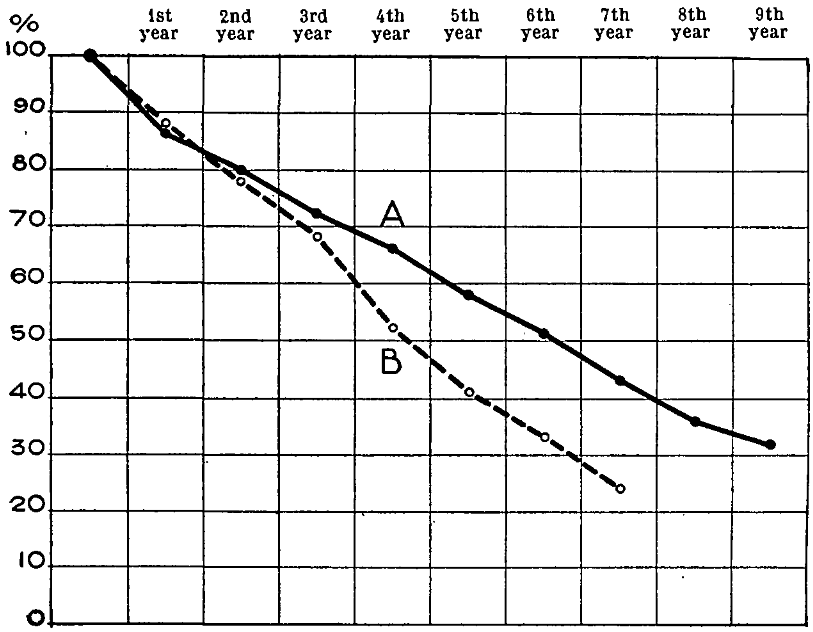
Ante-primary silicosis is regarded by us as the earliest stage at which we can recognise a dust-phthisis as a specific clinical entity. Our miners' phthisis compensation is not based directly on the principles of accident compensation, consequently we do not require a subject to be disabled before being compensated. The data on which the graphs are based are taken from the Annual Reports of the Miners' Phthisis Medical Bureau. After six years only 156 survived as ante-primary silicosis, while 107 were dead—in the great majority of cases, of tuberculo-silicosis. The remaining survivors have progressed beyond the ante-primary stage, although nearly all of them gave up underground work on these mines when they were notified as suffering from the disease. With us, as elsewhere, the tubercle bacillus is the dominant infective factor in disability and death related to dust-phthisis. Dust-phthisis has always been with us on these fields, but a change in clinical type has been observed as the years go by.



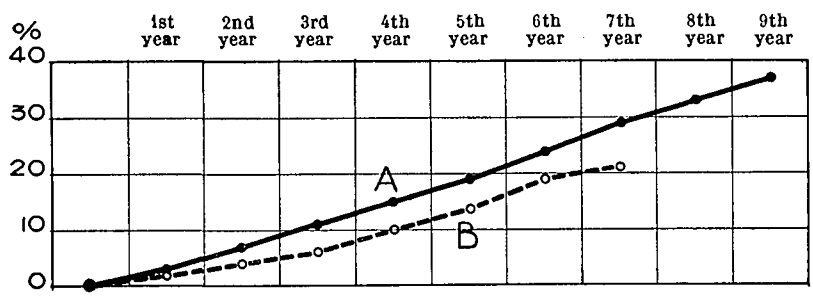
No. 1. — Progression chart of 895 cases diagnosed as *Simple Silicosis* in 1920. Height of columns presents proportion surviving as *Simple Silicosis* for consecutive periods of twelve months.



No. 2. — Progression chart of 473 cases diagnosed as *Ante-Primary Silicosis* in 1922. Height of columns presents proportion surviving as *Ante-Primary Silicosis* for consecutive periods of twelve months.



No. 3. — Taken from Nos. 1 and 2. The progression curves of " Primary Silicosis (A) and " Ante-Primary Silicosis (B) compared. There is no gain in ability to arrest the disease.



No. 4. — Death curves of " Primary Silicosis " (A) compared with " Ante-Primary Silicosis " (B). There is a gain in expectation of life for ante-primary cases.

In the earlier days the dust was the dominant factor and the outstanding features were dyspnoea with cardiac-failure, dropsy, and oedema of gravity distribution. The disease, while much more prevalent, was running a different course. For many years past the disabled cases have been much more like an ordinary chronic tuberculosis, and the infective factor has been dominant. Some years ago the Medical Bureau introduced the term " silico-tuberculosis " to distinguish cases in which the infective factor was dominant from the cases of tuberculo-silicosis in which the dust factor was dominant. My colleagues, Drs. A. Sutherland Strachan and F. W. Simson, both of whom have had a wide post-mortem room experience of dust-phthisis, urge me to insist on the fact that the distinction between tuberculo-silicosis and silico-tuberculosis is clinical and not pathological. They point out that the lesion of tuberculo-silicosis is a specific pathological lesion and is neither the lesion of tuberculosis nor the lesion of silicosis. It is the same now as in hundred-year-old museum specimens. They add that there is no such thing as the specific lesion of silico-tuberculosis. With these contentions I of course agree; but one does not drop a term or classification that is useful clinically solely on the grounds that it does not fit in with pathological categories, nor have clinical terms always been introduced with an aftercoming pathologist in mind: one may perhaps add that a dust-phthisis does not start in the post-mortem room.

It might also be argued that what Dr. W. Watkins Pitchford has called the " gross characters of the silicotic lung " may differ in the two types of case. The " old " lungs were typically bulky; emphysema was present, but was far from being solely responsible for the bulk. The lungs, apart from the characteristic lesions of tuberculo-silicosis, rather suggested a pigmented fibroid phthisis, but they were twice the size they ought to be. The present lungs are not typically bulky, while emphysema plays a larger part in their bulk than it did in the old lungs, which did not collapse when removed from the body but stood up like plaster casts. I have discussed this question with Dr. Louis Irvine, the present Chairman of the Medical Bureau, and we both agree that, since the term " tuberculo-silicosis " fits both the clinical and pathological categories, it is misleading to bring into literature a term such as silico-tuberculosis that fits the clinical categories only. It is for this reason that Dr. Irvine himself has never liked this term.

The association between tuberculosis and dust-phthisis is proverbial, but the variation in the part played by tuberculosis is almost equally proverbial. It is misleading to deduce the " silicosis rate " of an industry from its tuberculosis rate, even if one counts tuberculo-silicosis as tuberculosis. In many phthisis-producing industries tuberculosis does not become an important factor till well into the sixth decade of the worker's life and after getting on for thirty years of employment, yet a systematic examination of employees will disclose plenty of simple silicosis. An instance of such a state of affairs has been splendidly reported by Drs. E. R. Hayhurst, D. T. Kindel, B. E. Nyswander, and C. D. Barrett in the *Journal of Industrial Hygiene*, Vol. XI, 1929, p. 228. These observers point out that they were dealing with an open quarry, but, after all, silicosis was first systematically studied and its association with tuberculosis first satisfactorily defined in the case of workers in open quarries [1].

It is not difficult to recognise factors in a dust-phthisis which predispose to infection of lungs, but it is very difficult to see why identifiable factors should operate so differently.

I have been impressed by the following observations made chiefly on native miners. While dust of SiO_2 possesses the ability to settle permanently in the hostile territory of the lungs, this ability is only relative. In the case of a native who has worked many underground contracts on these fields and has died immediately on his return from his kraal, it is surprising how little *pigment* there *may* be in the lungs. If a native who has worked many underground contracts dies of pneumonia immediately on his return from his kraal the pulmonary alveoli will be found to be swarming with pigment-laden and silica-laden cells. These cells will have been loaded up months before and yet have remained sufficiently handy, sufficiently free and sufficiently well preserved to be poured into the alveoli. I incline to think that these cells have remained in the fluid but stagnant lymph of obstructed lymphatics, and that lymph persists for a long time fluid but stagnant in a distended obstructed lymphatic. The history is the same as that of a thrombosis: ultimately organisation occurs in each case. If invading pathogenic organisms be met by stale humoral and cellular elements, their survival would be facilitated. To borrow a term Professor Lyle Cummins has used in connection with tuberculosis, the effective occupation of an area of lung by a phthisis-producing dust sets up a " dead area " in the sense that this area is out of the free circulation.

---

[1] *Trans. Med. Chirurg. Soc. of Edinburgh*, Vol. I, 1824, p. 373.

One more feature may be adduced to illustrate the interference in normal lymph circulation that follows on effective occupation of the lungs by a phthisis-producing dust. Dr. Harvey Pirie and I have been much impressed by the promptness and ease with which inhaled dust gets past the lungs to be held up elsewhere. We have described what we call the silicotic or tuberculo-silicotic zone, and this zone includes glands in the portal fissure and glands round the stomach and pancreas as well as glands above the diaphragm other than the trachaeo-bronchial groups. The phenomena described—retention in the lung, mobility in the lung, and interference with the normal flow of lymph—are all such as should favour infection, but why do not they function more uniformly ?

Before leaving the subject of phthisis-producing dust and its adulterants, I would emphasise my belief that intermittent employment is the most effective single measure against a phthisis-producing dust making a dust-phthisis. The simple silicosis rate is comparatively low in our native miners, most of whom are employed intermittently, and I relate this low rate to the fact that even a phthisis-producing dust before being finally fixed remains for some time under conditions that enable some of it to get out of the lung in favourable circumstances. Such favourable circumstances are intervals between periods of underground work of sufficient length to enable elimination to retard accumulation.

In this context the following feature may be recalled. Greenfield, later on Ziegler, and in recent times Collis and others, have called attention to the fact that although a dust-phthisis is a "dry" disease and a disease of the terminal portion of the bronchial tree, the small bronchioles are involved in the trouble and shed their epithelium. Intervals from exposure to a phthisis-producing dust affords this section of the lung's eliminating apparatus an opportunity for regaining lost efficiency.

To turn from the agent to the subject. To begin with, the initial examination of recruits to the mining industry that has been our practice since 1916 has amply justified the selection of men with good general physique and unimpaired respiratory apparatus. With exposure to a phthisis-producing dust, as in other circumstances, it is a case of one is taken and the other left. Workers differ greatly both in the ability to get rid of dust and in their ability to resist tuberculous and other super-imposed infections. While writing this paper I have seen the lungs of two miners, one native and one European. Each had worked sixteen years underground and on machines; neither had a clinical silicosis. In both cases there was comparatively little pigmentation of lungs, and the native did not present the slightest suggestion of macroscopic silicotic lesions while in the European such macroscopic lesions as were recognisable were confined to the roots of the lungs.

The part played by the tuberculous factor varies from one phthisis-producing district to another. With us the tuberculous factor is perhaps the most serious aspect of the problem: so many of our men, although they give up mining, pass rather rapidly from silicosis without disability to silicosis with disability, and so on to tuberculo-silicosis. Some observers relate this phenomenon in part to difference in physical type and compare the short stocky Cornishman and his long-drawn-out simple silicosis with the tall lanky South African and his rapid development of the infective clinical type of the disease. I would also associate this difference in behaviour with the fact that the industrialisation of pastoral and agricultural districts is always associated with an initial rise in their tuberculosis rate. This initial rise is followed by a fall. The Western areas of the United States of America and Japan are modern instances. At present over 70 per cent. of our European underground complement are South African born, but this class only took up mining in considerable numbers since 1907. Before 1907 our European underground complement was drawn almost entirely from overseas. Other things being equal, the members of an underground complement with traditional spontaneous discipline will look after themselves better than those of a complement with no mining tradition.

The third factor for consideration in dealing with the causation and progression of silicosis or dust-phthisis is the conditions of work. The important part played by intensity and duration of exposure, and, in my opinion, by continuity of exposure, may be taken for granted. I am going to refer to conditions related to methods adopted for reducing intensity of exposure to dust and infection. At about the same time British and South African authorities were attempting to deal with risks due to dust underground. With the British it was coal dust and colliery explosions; with us it was silica dust and silicosis. Each party was confronted with the original choice between wet and dry methods. The British adopted dry methods and rendered coal dust non-explosive by mixing it with inert dust in preference to by wetting it. They were, of course, alive to the risk of introducing a phthisis-producing dust. Fifteen years' experience has shown that the method adopted has put a stop to colliery explosions without raising the respiratory diseases rate of employees. It is quite possible that systematic examination of colliers will disclose silicosis or dust-phthisis without disability, but the method has justified itself.

South Africa chose wet methods. Circumstances alter cases and, on the Rand, we have neither colliery lay-out nor colliery ventilation as the given manœuvre ground. Up to a point the method adopted has been a success; the amount of air-borne dust has been greatly diminished and the incidence of silicosis has fallen. The reduction of dust by watering cannot, however, have all the credit for the fall in silicosis incidence; one must remember the important part played by improvement in ventilation and by selection of employees (" initial examination ").

When one considers conditions of exposure as a factor in the causation of dust-phthisis, one remembers that this disease may arise in open quarries, workshops or mines. The peculiarity of conditions on the Witwatersrand lies in the following combination of factors:

Men are working at a high temperature with a high relative humidity.

Nearly all underground employees, both European and native, are drawn from a population occupied until recently with agricultural and pastoral pursuits.

The working population is, comparatively speaking, highly tuberculised. At any one time there will be rather over 9,000 Europeans and rather over 150,000 natives at work underground. The annual tuberculosis incidence on native miners is about 700 per 100,000 per annum. Opportunity for contact with tuberculosis is greater than usual.

Is this peculiarity in conditions associated with any peculiarity in the disease ? One may say that the incidence rate of simple silicosis is not unduly high, but two points call for mention.

In the case of those affected, the mean duration of exposure before the disease is detected is about twelve years.

A large proportion of the cases pass on to the infective progressive type of the disease not long after the condition has been recognised in its simple form.

Granting that one takes on an occupation with an occupation hazard, there is a vast difference between risking disablement early in the fifth decade and risking disablement late in the sixth decade. When one remembers that but few South-African-born Europeans start underground work before they are twenty-five years of age, the fact that a serious proportion of those who contract silicosis are disabled in the first half of their fifth decade is the salient feature of silicosis on the Witwatersrand. The mean duration of exposure before the disease is detected is on the short side, and the comparatively brief accumulation period cannot be accounted for by intensity of exposure. It must be born in mind that the majority of the cases that progress have given up underground work. One is driven to the conclusions that in considering conditions of exposure as a factor in the aetiology of silicosis one must consider them under two heads:

(*a*) As a factor in simple silicosis.
(*b*) As a factor in infective silicosis.

I will dismiss simple silicosis without further reference and turn to the infective type of the disease. Granted that tuberculosis is, and always has been, the dominant infective factor in silicosis or dust-phthisis, one must accept the fact that the underground workers on the Witwatersrand present a favourable soil for the implantation of this disease. I am not satisfied that this is the whole story. When workers are not exposed to high temperatures associated with a high relative humidity, the disease does not behave as it behaves on the Witwatersrand. Reference has been made to the Kolar Mine Field. There one has a population susceptible to tuberculosis working at a high temperature but at very low humidity: there is no evidence of a high silicosis rate, still less of a high infective silicosis rate. Certainly the fine ventilation of the Kolar mine must be considered in assaying their favourable position in respect to silicosis; but I cannot help thinking that the adoption of wet methods of dust control means the giving of too much consideration to simple silicosis and too little to the more formidable infective type of the disease.

In 1918, and again in 1929, Dr. J. S. Haldane called the attention of the Witwatersrand to the price that had to be paid for keeping down dust in a mine by water. As far as the recognised methods of estimation of dust can tell us, our workers are not exposed to higher concentrations than are workers elsewhere. Water has not failed in this respect. The fact remains that the disease with us is made rather more quickly and in a more vicious form than is the rule elsewhere. I cannot think that our experience on the Witwatersrand will encourage others to add a high relative humidity to other conditions of exposure to a phthisis-producing dust if they can possibly avoid doing so. As has been pointed out in another communication to this Conference [1], our selection of wet

[1] "Historical Review of Mining Conditions on the Witwatersrand", p. 107.

methods of dust control was largely dictated by our circumstances. Our *damnosa haereditas* did and does prevent us from realising colliery or Kolar ventilation conditions. What is left ? Dr. Haldane urges us to seek the " inanimate antidote ".

Remembering my audience, I have discussed the aetiology of silicosis or dust-phthisis in terms of mining in quartz; the condition of which I have first-hand experience. Members from overseas are far better qualified to discuss other aspects than I am myself. There is good reason to believe that colloidal silica is as dangerous as, if not more dangerous than, crystalline silica. Experience in the manufacture of certain abrasive powders suggests that certain colloids favour the production of silicosis when present in the air with SiO_2. The investigators at the Amherst Quarries, Ohio, suggest that certain colloids hinder the production of silicosis and particularly of tuberculo-silicosis when present in the air with SiO_2. Since the war, attention has been directed to asbestos as a cause of dust-phthisis. If South Africa is to become a centre of diamond cutting and polishing it may have another dust-malady in which to be concerned.

To *summarise:* when dealing with the aetiology of silicosis or dust-phthisis:

(A) One considers intensity, duration and continuity of exposure to phthisis-producing dust.

(B) One remembers that the association of adulterants animate and inanimate may influence both the production of the disease and its type.

(C) One fears that a high humidity favours infection by prolonging the life of pathologic organisms outside the body and facilitating their entrance into the body.

(D) One asserts that infection in a phthisis-producing industry should be thought of as it is thought of in a surgical ward or operating theatre.

(E) One feels that if a pastoral or industrial population is to turn to industry, they should think twice before turning to a phthisis-producing industry.

A PRELIMINARY STUDY OF THE PATHOLOGY OF SILICOSIS AS SEEN ON THE WITWATERSRAND

BY A. SUTHERLAND STRACHAN, M.A., B.SC., M.D. (GLASGOW), AND F. W. SIMSON, M.B., CH. B. (EDIN.), PATHOLOGISTS AT THE SOUTH AFRICAN INSTITUTE FOR MEDICAL RESEARCH, JOHANNESBURG

In this study, an anatomical basis of silicosis is outlined.
The development of silicotic lesions, both uncomplicated and complicated by infection is described.
The macroscopic features are detailed and the complications indicated.
A small series of experiments on the relationship between tuberculous infection and silicosis is incorporated and a tentative conclusion arrived at.

ANATOMY

In the routine examination of a large series of lungs for silicosis and tuberculosis our attention was early drawn to the occurrence of pigmentation in the pleura, in the interstitial tissue and apparently in the lung parenchyma, and an explanation was sought for this phenomenon. The explanation was found to lie in the distribution of the lymphatics and of lymphoid tissue in the lung. For this reason it appears to us that a review of the anatomy of the lung with particular emphasis on the lymphatic apparatus is an essential preliminary to the study of the pathology of silicosis.

For our purpose it is sufficient if we consider the bronchi, lungs and pleurae.

The intra-pulmonary bronchi divide and subdivide throughout the lung and terminate in the lobular bronchioles. The bronchi and bronchioles are lined by ciliated epithelium. The bronchiole is succeeded by a slightly dilated portion known as the vestibule, in which the epithelium alters to a flattened type. The vestibule divides into several passages from three to six in number—the atria; these open out into two or more somewhat elongated passages —the infundibula, from which arise the alveoli or air-cells.

The lung parenchyma consists of lobules, which, though quite distinct from one another, are intimately bound together by connective tissue, the interlobular septa.

A terminal bronchiole with its subsequent divisions and air-cells and with the associated blood-vessels, lymphatics and nerves, forms the lobule.

Both lungs are covered by a thin transparent serous membrane which encloses the organ except at the root.

Beneath this membrane is a delicate connective tissue in which are to be found elastic fibres, blood-vessels, nerves and lymphatics; the subserous connective tissue is continuous with the trabeculae of the lung parenchyma.

In our experience early pigmentation occurs in certain definite sites in the lungs and pleurae; these sites are in the lymph-glands, in the sub-pleural tissue, in the interlobular septa and in the parenchyma in relationship to the terminal bronchioles, to the vestibules and to the atria.

The lymph-glands into which drain the lymphatics of the lung may be divided into four groups:

(*a*) Broncho-pulmonary.
(*b*) Superior tracheo-bronchial.
(*c*) Inferior tracheo-bronchial.
(*d*) Paratracheal.

The broncho-pulmonary glands lie in sites between a lobe of the lung and its bronchus.

The superior tracheo-bronchial group lies in the upper angle between the trachea and the main bronchus.

The inferior tracheo-bronchial group lies in the lower angle formed by the main bronchi at the bifurcation of the trachea.

The paratrachial group lies along the trachea in relation to the inferior laryngeal nerve.

The lymphatics of the lung are divided into two groups, superficial and deep.

The superficial forms a wide-meshed net-work in the subpleural connective tissue over the whole surface of the lung. From this net-work channels pass to the broncho-pulmonary glands at the root of the lung. Oppel [1] states that in addition to these channels, many small lymphatics pass from the superficial vessels by way of the interlobular septa to join the deep vessels arising around bronchi and blood vessels.

[1] OPPEL: *Lehrbuch der vergl. Mikr. Anat. der Wirbeltiere*, 1905, p. 746.

Scott and Beattie [1] remark that: "the superficial plexus is almost independent of the deep except at two points" but they do not mention where the points of communication are.

Miller [2] states:

> In the human lung there are connective tissue septa much more largely developed than those about the primary lobules, which separate the secondary lobules from each other. In these septa blood and lymph vessels are associated with each other and *where they join the pleural vessels* [3] there is always found a mass of lymphoid tissue.

Our observations have led us to the conclusion that communications between deep and superficial lymphatics must exist in order to account for the distribution of pigment in the interlobular septa and in the pleura. This distribution, in our opinion, is mainly in relationship to the perivenous lymphatics. The transport of pigment for any distance in the lung parenchyma is intra-cellular and by way of lymphatics and for this reason the early pigmentation of pleura implies communication between deep and superficial lymphatics.

The deep lymphatic vessels take origin in relationship to the branches of the bronchi and of the blood-vessels and terminate in the tracheo-bronchial glands.

According to W. S. Miller, lymphatics cannot be demonstrated in the branches of the bronchi beyond the terminal bronchiole except they be in relationship to the artery or vein.

In the larger bronchi the lymphatics form two plexuses—an inner sub-mucosal, and an outer peribronchial beyond the cartilages; as the branches of the bronchi become smaller the peribronchial plexus gradually disappears and only the sub-mucosal persists.

The pulmonary artery follows the bronchus in all of its subdivisions, dividing as it subdivides; each has its own system of lymph vessels and these are in communication at the places where the bronchus divides and at the distal end of the vestibule.

The pulmonary veins have also a system of lymph vessels which, like the arterial, are in communication with the bronchial system where the bronchus divides and also at the distal end of the vestibule where the bronchial system begins.

In the primary lobule of the lung, the bronchiole and the artery lie in the centre while the veins occur mainly in the periphery, only the venous radicles from the vestibule form veins within the lobule.

---

1 Scott and Beattie: *Jour. Path. and Bac.*, Jan. 1928, Vol. XXXI, p. 54.
2 Miller: *Anat. Rec.*, 1911, Vol. V, p. 99.
3 The italics are ours.

As yet no lymphatics have been demonstrated in the walls of the alveoli. It is our opinion that lymphatics do not exist in this situation.

The examination of sections of carcinoma of the lung showing extensive lymphatic permeation revealed no involvement of the alveolar walls (*vide* fig. 1[1]). Further, the absence of pigment in the alveolar walls in early cases of pigmentation without alveolar fibrosis is, in our opinion, in favour of the view that lymphatics do not exist in this situation.

In association with and intimately related to the lymphatics of the lung, there occur aggregations of lymphoid tissue, which may be in the form of simple aggregations, follicles or nodes.

This tissue is found in sites sub-pleural, peribronchial, periarterial and perivenous.

In the sub-pleural region the lymphoid tissue occurs as simple aggregations irregularly distributed, but showing very often at the points of junction of interlobular septa with sub-pleural connective tissue.

Lymph nodes and follicles are found on the larger bronchi where branching takes place; in the smaller bronchioles lymphoid aggregations, not follicles, are seen outside the muscular coat, lying between the bronchiole and the artery.

Lymphoid aggregations occur along the artery and then usually lie between the artery and the atria, not between the bronchus and the artery as in bronchial lymphoid tissue.

The perivenous lymphoid tissue is found commonly where a small vein joins one of the main trunks of the pulmonary vein; consequently these aggregations are frequently best seen in the interlobular connective tissue septa.

In this outline of lymphoid tissue of the lung we have followed W. S. Miller's [2] description, which corresponds in the major details with the description given by Oppel [2] and which is accepted and confirmed by Scott and Beattie [2] in their recent work on tuberculosis in primates.

We are able also to confirm the observation made by Miller [2] that in miliary tuberculosis the tubercles appear where he has described the normal occurrence of lymphoid aggregations.

Further, it is in these situations that the arrest of pigment akes place in the earliest stages of the development of silicosis.

---

[1] The illustrations (figs. 1-14) are given after p. 248.
[2] *Op. cit.*

As regards the epithelium lining the air vesicles the literature has been discussed in full by Cappell [1], and we agree that the lining consists mainly of nucleated squames and the lipoid-containing " septal cells ".

Cappell [2] states that the alveolar phagocytes are derived from these two types of cell, and that some time after separation from the alveolar wall they become indistinguishable from one another.

A feature of importance in these cells is the presence of lipoid granules in the protoplasm.

The Development of Simple Silicosis

We have emphasised the importance of the lymphatic apparatus in the development of silicotic lesions, but before proceeding with the discussion of the development, it may be worth while recapitulating the main features of the defensive mechanism, which acts in the prevention and limitation of the invasion of the lung by dust.

In the nose and nasopharynx the anatomical structure provides a very efficient dust filter for the inspired air; the dust that escapes arrest may settle on the mucous menbrane of the trachea and bronchi, whence by the action of the ciliated epithelium it is driven upwards and is removed in the sputum. Thus the air which reaches the alveoli, for all practical purposes, may be considered dust free.

Several factors may play a part in breaking down the defensive mechanism; of these, infection-producing disquamation of the epithelium of the upper air passages is an important one, while a great increase in the dust content of the inspired air may be another. In an atmosphere loaded with particulate matter, the filtering mechanism of the nose and nasopharynx is overcome, the lining epithelium of the upper air tubes becomes clogged and the air entering the alveoli contains relatively large amounts of dust. In our cases of silicosis both factors mentioned play a part, but the dominant one appears to be the great increase in the inspired air of respirable particulate matter. The greater part of the dust which finally reaches the alveoli, according to most authorities, is of a size comparable with that of pathogenic bacteria.

---

[1] Cappell: *Jour. Path. and Bac.*, July 1929, Vol. XXXII, p. 697.
[2] *Op. cit.*.

In the reaction to the invasion of the alveoli by dust, phagocytosis is the essential feature and this is associated with proliferation of the lining epithelial cells, which become detached from the walls to form the alveolar phagocytes.

In the conditions under which miners work on the Rand, there is in the air, in addition to siliceous particles, a considerable quantity of finely particulate carbon; both are found associated in the development of silicotic lesions. The alveolar phagocytes or " dust cells " become pigmented by the carbon particles (pigmentation may occasionally be seen in cells still *in situ* on the alveolar walls) and the silicotic lesions also show a similar pigmentation. This pigmentation is of considerable help in tracing the development of the lesions as the siliceous particles are frequently so small that even investigation by polarised light is unsatisfactory.

At this stage it is worth while recalling the fact that not all dust which reaches the alveoli is retained within the lung parenchyma. Some of the cells which contain it reach the lumen of the bronchi and are removed in the sputum. The alveolar " dust cells " tend to accumulate in the small air passages—atria, vestibules and smaller bronchioles, and from there they pass into the tissues of the walls to the lymphatics. In our investigations we have not been able to demonstrate dust cells in the alveolar walls except in cases where there is a generalised fibrosis, probably of infective origin. We have, however, constantly noticed their accumulation in the small air passages, apparently just prior to their entrance into the lymphatic system. The first sign of the arrest of " dust cells " occurs at very definite sites in the lymphatic system—where lymphoid tissue has been described as occurring in the normal lung. In the earliest stage of the process the first places of arrest appear to be in lymphoid tissue about atria, vestibules and terminal bronchioles as the lumen of one or more of these structures can usually be seen in close relationship to the aggregations of "dust cells " (*vide* fig. 2). In our experience the true silicotic formation does not occur as a rule in relation to the larger bronchi. That the perivenous lymphatics are also involved in the process is obvious from the fact that the periphery of the lobule becomes delimited by deposits of pigmented cells and that interlobular septa and pleura also show the cell aggregates. With the exception of the subpleural connective tissue, however, true silicotic nodule formation is rarely seen in these situations.

An interesting and important feature noted in the bronchiole related to the pigmented cell aggregates in the peribronchial lymphatics, is the occurrence of desquamation of the ciliated epithelium (*vide* fig. 3). This " dry " bronchiolitis is a constant feature and may be an important determining factor in the lung invasion. It is also worthy of consideration from another point of view; the radiological examination of miners has revealed a condition which is, in the majority of cases, definitely presilicotic, and which is associated with a characteristic picture known as " fine ramifying fibrosis ". This shows an appreciable increase in the extent of the shadows originating at the hilus of the lung and spreading fanwise into the lung substance. In the normal lung these shadows show the same distribution as the larger bronchi and possibly blood-vessels, but in radiographs showing increase the definition of the main trunks is better, and in addition shadows are seen extending almost to the periphery. The picture has previously been explained by postulating a diffuse fibrosis occurring in peribronchial and perivascular tissues associated with a mantling of bronchi and vessels with dust cells. In our experience the mantling of these structures with dust cells is not a constant feature even in moderately advanced cases of silicosis. It seems to us that some other explanation is required and for this reason the problem is being investigated. For the present, however, we would lay emphasis on the occurrence of the dry bronchiolitis which manifests itself before actual microscopic silicotic foci can be demonstrated.

The effect of arrest of the pigment-laden phagocytes has been described to be associated with a reaction which increases the lymphoid tissue. This increase has been noted by many observers, and by some, follicle formation with adenoid reticulum has been described. Lymphoid follicles in relationship to the smaller air passages were described as normal by Klein [1], though W. S. Miller [2] maintains that follicle formation in these sites does not occur apart from pathological changes. This increase may occur in the sites at which the pigmented cells of silicotic lesions are arrested. In the majority of cases we have not been able to demonstrate the increase in lymphoid tissue as it is almost certain to be obscured by the preponderance of pigmented cells. The further reactive phenomena seen in the early silicotic lesion becomes comparable with those which take place in a lymph gland, which is the seat of invasion by dust cells.

---

[1] KLEIN: Quoted by Miller: *Anat. Rec.*, 1911.
[2] *Op. cit.*

In the early pigmented mass, in suitable preparations, an occasional cell is seen to contain fatty material in addition to pigment. The fatty material may be an original element in the cell, as phagocytes derived from septal cells usually contain fatty material, or it may be a manifestation of degenerative changes taking place prior to disintegration of the cell. This appearance of fat in the earliest cell aggregations is, in our opinion, of considerable importance, for fat is present in all stages of the development of the true silicotic nodule. In the fully developed silicotic focus the fat is mainly extracellular, and this we take as presumptive evidence that the dust cells die and disintegrate. In addition to this, we have noted calcification of symmetrical character in some of these foci (*vide* fig. 4).

The silicotic nodule develops in the pigmented cell aggregate and appears as a small ball of well-formed fibrous tissue; only when this change takes place is the term silicotic nodule used.

On disintegration the phagocytes set free the irritant dust, which provides the stimulus for the reactive fibroblastic phenomena of silicosis. The cells taking part in the reaction are probably derived from the adventitial tissues of bronchiole and blood-vessel. If follicle formation occurs, as has been described, part of the fibroblastic reaction may be derived from the reticulum. Herring and MacNaughton[1] in their investigations of the lymphatic system in relation to the removal of particulate matter from the lymph stream summarise their conclusions as follows:

> The phagocytic cells are arrested in the first lymph gland in the lymph stream. The cells carrying solid particles pass from the lymph sinuses of the gland into the lymphoid tissue of the cortex and medulla and eventually discharge their burden among the lymphocytes there.
>
> The lymph gland is an extremely efficient filter and only allows solid particles to pass through it when these arrive in too great numbers at a time, or when the gland has become disorganised.
>
> The lymphocytes of the lymphoid tissue act as a mechanical barrier against the particles and eventually the barrier is made more complete by the appearance in it of fibroblasts and the formation of fibrous tissue.
>
> The foreign material is firmly enclosed, while the lymph sinuses are left open for the free passage of lymph.

The efficient filtering action of the lymph gland demonstrated by Herring and MacNaughton[2] probably also applies to the lymphoid tissue in the lung. The phagocytes are arrested and the pigment incarcerated while the lymph channels remain clear.

[1] HERRING and MACNAUGHTON: *The Lancet*, 3 June 1922, p. 1081.
[2] *Op. cit.*

As the first lymph gland in the stream is first involved and then the next in the series, so in the lymphoid tissue in the lung, viz. the aggregations in relation to atria, vestibules and bronchioles are first to show the reaction.

The lymphoid hyperplasia, which, as Herring and MacNaughton [1] conclude, acts as a mechanical barrier to the onward passage of the dust-laden phagocytes is followed by a fibroblastic reaction and a fibrosis.

The Development of the Silicotic Nodule in Lung Substance

In the aggregation of pigmented cells a small focus of fibroblasts appears (*vide* fig. 5). It may be oval or circular in shape and may occur in the centre of the aggregation or quite eccentrically; the site of its appearance is quite fortuitous but once initiated the succeeding changes proceed from this centre of origin (*vide* fig. 6). In some cases, the reaction appears almost of a granulation tissue type (*vide* fig. 7), but in the majority of cases there is little new formation of blood vessels. The earliest microscopic nodule is a very minute cellular fibroblastic accumulation of cells, arranged irregularly, some cells radially, some at the periphery arranged tangentially, and surrounded by pigmented dust cells and lymphocytes. The fibroblasts show little if any pigmentation. It would appear that the greater part of the carbon pigment is removed from the site in which the fibrosis is developing while siliceous particles are retained. This is a feature which can be demonstrated from the minute cellular focus to the well formed nodule.

The cellular character persists for a period during which the focus is enlarging, but soon collagen fibres are laid down and a ball of well formed fibrous tissue appears, which is surrounded by zones of fibroblasts, dust laden pigmented cells and lymphocytes. The fibrous tissue is arranged in a whorl-like manner in the central portion while at the periphery the appearance is that of concentric lamination. The increase in size of the nodule is always at the periphery by concentric lamination (*vide* fig. 8).

There are two striking features in the well-formed silicotic nodule—the absence, in the majority of cases, of appreciable quantities of carbon pigment and the presence of fat. With regard to the absence of pigment the nodule from the lungs of the Rand miner differs from specimens of British material which we have examined.

[1] *Op. cit.*

As to the fat, this makes itself manifest as soon as fibrosis takes place and increases in amount with the advance of the fibrosis. We have noticed that frozen sections show appearances suggestive of changes preliminary to calcification; the haematoxylin stain shows an alteration in the colour reaction of the material varying from the normal, through varying tints of violet right up to the intense bluish black of calcification. The tissue apparently contains a substance, which is readily soluble in the reagents used for the preparation of ordinary paraffin sections, for these show alterations of the staining reaction only when calcification is complete. Presumably some soap soluble in the reagents is a stage in the calcifying process, and this soap when brought into contact with the haematoxylin stain in frozen sections gives the modifications which we have noted.

Our opinion is, therefore, that in a considerable number of instances, changes just preliminary to calcification may be present in silicotic foci though not demonstrable by the ordinary paraffin section methods. In the advanced silicotic islet, calcification may occur and usually is in the centre and appears to be a condition quite apart from infection (*vide* fig. 4). A further noteworthy point in regard to the silicotic nodule is that, in some sections, the aggregation of dust cells appears to be surrounding pulmonary blood vessels and air tubes, and this suggests the possibility of subsequent fibrosis bringing about obliteration of the lumen. In our investigations the appearance of the fibrosis and its development do not suggest that obliteration occurs to any great extent in simple silicosis; the fully formed fibrous tissue islet appears to displace structures rather than to surround them.

The islets of fibrosis increase in size by a laminated type of growth at the periphery until ultimately they are readily detectable by the naked eye and are easily palpable. Though microscopically the fibrous tissue may show little or no pigmentation, the zone of arrested phagocytes at the periphery imparts a definite black colour to the naked eye appearance. The contrast between macroscopic and microscopic appearances is thus very striking.

As the condition of simple silicosis progresses, the nodules not only increase in size but also in number, so that there may be nodules in various stages of development in one lung, but they are all of the type described above.

We have mentioned that in the earliest stages the aggregates of dust cells occur in relationships to bronchioles, vestibules and atria. A silicotic focus may arise in one or more of these sites. If they arise simultaneously, in their growth they may become contiguous and then confluent, producing a " composite nodule ". This is seen macroscopically and palpated as a single nodule (*vide* fig. 9).

It has been stated that the nodular fibrosis produces an appearance which has been likened to a " string with beads on it ". In our opinion the simile is not quite accurate. The arrangement is rather that of a staphyloid type; each element consisting of a silicotic nodule, single or composite, situated at the entrance to a lobule.

In some macroscopic specimens of simple silicosis there are seen massive areas of fibrosis, which superficially resemble similar areas to be described in infective silicosis. Close examination may reveal a nodular basis for the massive areas. Microscopic sections show numerous contiguous single and composite silicotic nodules between which there still survive some of the lung structures, e.g. bronchi, blood vessels and alveoli. In this type of lesion collapse of lung tissue occurs which may be the result of narrowing of the lumen of bronchus or bronchiole or more probably the result of displacement of tissue by the great number of nodules (*vide* fig. 10).

Changes in the Pleura

While the changes, which have been described, are taking place in the lung substance, similar changes occur in the subpleural tissue. These in the order in which they occur are — arrest of dust cells in aggregations, fibroblastic reaction and finally fibrosis with the formation of an islet surrounded by pigmented cells and lymphocytes. The process is modified, however, as soon as the islet reaches the surface. In the subpleural tissue it is entirely surrounded by pigmented cells, but when the fibrous tissue in its growth reaches the serous membrane, the pigmented cells become displaced, leaving that portion which projects on the surface free from these pigmented cells (*vide* fig. 11). In some of the older subpleural nodules the endothelial cells of the pleura have disappeared, and at that point the fibrosis is of a denser character and greater in amount. This suggests that the change is partly induced by friction of the opposing pleural surfaces. The macroscopic appearance of the silicotic islet from the pleural aspect is that of a small pearly white, slightly raised area and is then known as the " subpleural plaque ". In the morbid anatomy of silicosis the subpleural plaque is a feature of some importance, and we emphasise here that it is simply a nodule of silicotic fibrosis originating in subpleural tissue. It only involves the pleural membrane secondarily, in the course of its increase in size. Its site is probably determined, as in the lung, by the presence of lymphoid tissue; its development by the invasion of this tissue by dust cells.

Changes in Lymph Glands

Dust cells from lung and pleura are transported to the tracheobronchial and broncho-pulmonary glands respectively, and are arrested there. When the lung is invaded by dust, some of the phagocytes escape arrest in the lung foci and are carried by way of the lymphatics to the root of the lung. Probably only a few cells escape at a time from the region of each pigmented focus, but the sum of these cells from all foci is large. There is thus a relatively massive concentration of dust cells in the lymph glands. This concentration explains why gross pigmentation occurs in the root glands while lung and pleura still show relatively small amounts.

The pigmented cells pass from the afferent lymphatics into the sinuses and from there to the cords and nodes in the cortex and medulla of the gland. The dust cells die and disintegrate, set free the irritant particles which give rise, first, to lymphoid hyperplasia, then a fibroblastic reaction and finally a localised fibrosis. The nodule at this stage is similar in type to those seen in the lung or pleura. In some cases a dense hyaline change is seen presenting features which superficially resemble amyloid tissue, but sections of this material suitably stained give a negative result. The nodules occur in multiple sites in gland tissue, and there arise numbers of single islets which may coalesce to form composite islets, or in a further stage areas of massive fibrosis. This brings about destruction of the normal gland elements. Even when replaced by massive fibrosis, dilated lymph channels may be seen at the periphery.

In a proportion of cases calcification occurs without obvious signs of tuberculous infection. The changes we have observed in dust-occupied gland tissue are in agreement with the conclusions of Herring and MacNaughton [1] on the arrest of particulate matter in lymph glands.

The similarity between the changes seen in lymph glands to those which occur in lung substance and pleura is a further point in support of the view that the silicotic foci begin in lymphoid tissue in the lung substance.

[1] *Op. cit.*

Gye and Kettle [1] show that local inoculation of silica into subcutaneous tissues produces a definite and characteristic reaction, but this reaction differs from that seen in lymph glands and in the lung tissue.

We can find no evidence that silica produces the lesion of silicosis in tissues other than lung and lymph glands.

Infective Silicosis

The lesions we have just described are, in our opinion, due almost entirely to the effect of inhaled dust. We have now to consider what modifications arise when infection is associated with silicosis.

Some of these modifications present definite features to which the term " infective silicosis " has been applied. Amongst infections the one that really matters is tuberculosis, though we have to admit that others may play a part both in the spread of the fibrotic process and in modifying its characteristic features. To what extent infection, apart from tuberculosis, is responsible for the changes in infective silicosis has not yet been determined, but the question is being investigated.

There are two main aspects of the relationship between infection and dust. In the former dust modifies infective processes; in the latter superimposed infection modifies the reactive processes produced by the presence of irritant dust.

In the lungs of miners who have worked underground in a dusty atmosphere, silica particles may be present in considerable numbers without producing macroscopic or microscopic silicotic nodules. The local tissue resistance of such a lung is so lowered that relatively small doses of a pathogenic organism may produce infection. Further, Mavrogordato [2] has shown, in experimentally dusted animals, that an unresolved pneumonia occurs in a proportion of cases when the animals are subsequently exposed to infection by organisms other than the tubercle bacillus. This may explain the relatively frequent occurrence of unresolved pneumonia in native miners, whose lungs show little or no evidence of silicosis. These manifestations are not included in the group " infective silicosis ", though they may be due to the modifications of the infective process by dust.

[1] Gye and Kettle: *Brit. Jour. Exp. Path.*, 1922, Vol. III, p. 245.
[2] Mavrogordato: *Publications of the South African Institute for Medical Research*, 1926, Vol. III, No. 19, p. 32.

Superimposed infection modifying the reactive processes produced by irritant dust is best seen in tuberculo-silicosis. Other organisms may play an important part in these changes, but up to the present it has not been determined to what degree.

The term " infective silicosis " should be confined to conditions in which infection produces changes in the reactions to dust.

As the tubercle bacillus is by far the most important organism which modifies silicosis, we shall confine our discussion to its effects.

Tuberculosis is essentially a disease of the lymphatic system, and when tubercle bacilli settle in the lungs they do so in lymphatic tissue. Miliary tubercles we have noted in sites in which lymphoid tissue has been described as normal; the same sites in which aggregate the pigment laden phagocytes which initiate the changes of silicosis. It is possible then, that the two reactive processes may occur simultaneously in relationship to one site. In such circumstances an islet of fibrosis of some size is produced relatively rapidly, but the fibrosis differs somewhat from the ball of well-formed, dense fibrous tissue of " simple silicosis ". In the centre of the islet the definition of the elements is lost, and appearances suggestive of central necrosis are seen, while at the periphery granulation tissue is more abundant. The typical tuberculous reaction, however, is absent. There is no follicle formation; no obvious aggregation of endotheloid cells and no giant cell formation (*vide* fig. 12). An islet may thus be the result of the combined process, and may be termed a tuberculo-silicotic islet; in this the tuberculous process is masked to a great extent.

In other cases the naked-eye appearances of an islet of similar size may suggest tuberculosis round the periphery, and this is confirmed microscopically. In this case infection had evidently occurred after the silicotic process had been well established.

It is difficult to estimate the relative incidence of the two types of tuberculo-silicosis.

The records of the Miners' Phthisis Medical Bureau show that a considerable proportion of miners, diagnosed as simple silicosis progress to the condition of tuberculo-silicosis. If they live long enough they die of tuberculosis, even if they have been removed from the working conditions in which the silicosis was set up. Of the cases diagnosed as simple silicosis on radiological and clinical grounds, some correspond with those, which are seen post-mortem to show the macroscopic features of simple silicosis and yet have the microscopic stigmàta of tuberculosis with silicosis. These are cases of tuberculo-silicosis even though diagnosed in the first instance as simple silicosis. The progress of the condition is slow, and although silicosis predisposes to tuberculous infection, it also has a limiting or inhibitory effect on the infection, as though the bacilli were incarcerated in the reactive fibrosis, or that the virulence of the organism was altered by the presence of silica. In other cases of simple silicosis, there is no tuberculous infection in the beginning, but this becomes superimposed later and tuberculo-silicosis is again produced. The terminal result is similar and it is this similarity which renders difficult the determination of the relative incidence of the two types.

The progress of the fibrosis in infective silicosis differs somewhat from that of simple silicosis. In simple silicosis we have shown that composite islets arise in relationship to the bronchioles, and that relatively large areas of fibrosis arise as a result of apparent confluence of contiguous islets in an area heavily affected by the silicotic process. What interstitial change does occur is almost certainly related to infection. A clean silicotic lung—admittedly a rarity—shows little change in the lung parenchyma beyond the silicotic foci and the changes in the air tubes.

In tuberculo-silicosis, however, we have a condition where increase of fibrosis occurs by direct extension. Lymphatics, interstitial tissue and alveoli may all be involved in this manner; although the lesion may be initiated as discrete islets, in time a diffuse fibrosis is set up. A considerable number of nodules may have been embedded in this tissue, but with the advent of necrosis and increasing generalised fibrosis their distinguishing characters are lost.

An area of diffuse fibrosis, generally designated " massive ", shows considerable pigmentation with carbon, irregular foci of necrosis and frequently some caseation. Giant cell systems and tubercle follicles are exceedingly rare. In frozen sections, fat may be demonstrated in considerable quantity.

Massive areas of fibrosis apparently arise in several ways.

In simple silicosis where numerous single and composite islets become contiguous the appearance simulates massive fibrosis. Although called massive, close inspection shows that it is composed of definite islets of fibrosis still retaining their distinctive nodular character (*vide* fig. 10).

A second mode of development arises in infective silicosis. In this too a nodular character may still be seen as the distinctive feature of the massive area, but unlike the simple type there is evidence of coalescence and minute foci of caseation may occur (*vide* fig. 13).

These two types may resemble one another macroscopically, in that each presents a greyish black coloration and has a nodular character. The points whereby they may be distinguished are evidence of coalescence of the nodules, distinct foci of caseation, and the colour is more grey in the infective type.

A third type of massive fibrosis is seen in which there is no evidence of nodular character. In this there is an ill-defined, diffuse necrosis. The colour is again grey from the combination of pigment, fat and necrosis (*vide* fig. 14). There may also be present areas of unpigmented necrosis. This is a manifestation of infection probably always tuberculous in origin. It is produced by the coalescence of numerous tuberculo-silicotic foci with subsequent breaking down of the tissue to form one mass. Often at the margin of such an area it is possible to distinguish the outline of some nodular foci.

Though tuberculosis may produce the modification which is known as tuberculo-silicosis, some cases in which silicosis is present show obvious local tuberculous foci. Sometimes they are unmodified and sometimes associated with an area of pigmented fibrosis. The condition may remain localised or there may be an acute terminal spread; silicotic lesions and tuberculous lesions occurring without one modifying the other.

Endarteritis obliterans has been described by some authorities as an essential factor of silicosis, but we have been unable to convince ourselves that this is so. In tuberculo-silicosis vessels may be obliterated in the progressive, massive interstitial fibrosis.

Macroscopic Appearance of the Silicotic Lung

When a miner dies and an autopsy is performed, the lungs are removed and sent to the Miners' Phthisis Medical Bureau for examination. This examination is essentially a macroscopic one; only in certain cases where confirmation is required is a microscopical investigation made. It is thus seen that from the practical administrative aspect, the macroscopic features of silicotic lesions are of considerable importance.

A minute silicotic focus in the lung in the earliest stages is not palpable, though the small pigmented islet may be visible; only on microscopic examination can fibrosis be detected. As the focus enlarges a stage is reached when it becomes palpable. On section of the lungs it projects slightly above the cut surface. The small palpable islet is the first macroscopic manifestation of silicosis in the lung substance.

It is obvious that, from the administrative point of view, the occurrence of an occasional small palpable islet cannot be held to constitute the disease silicosis. Certain degrees of the condition have therefore been determined which have been found to correspond with arbitrary stages in its progress, and with definite estimated degrees of disability. These degrees of silicosis are known under the terms, " slight ", " moderated ", " well-marked ", and " very-well-marked ". They indicate to the Bureau the relative number and size of the macroscopic lesions present in the lung substance. Thus in slight silicosis the lesions may be small and moderately numerous, or medium-sized to large and sparse; in the moderate degree the lesions may be numerous and small, or moderately numerous and large; in the well-marked degree, the lesions are numerous and large; while in the very well-marked degree they are very numerous and large.

In appreciating the degree present the whole lung substance has to be considered, for it is found that in a proportion of cases the lesions may be very limited in site, so that though they may be numerous and large where they occur, the greater part of the lung substance may be free from silicotic manifestations.

The terms small, medium-sized and large are used for islets of diameters up to 2 millimetres for the small, varying from 2 to 4 millimetres for the medium and from 5 millimetres to a centimetre for the large.

It is difficult to give a precise meaning to the words sparse, moderately numerous and numerous, as such a meaning could apply only in cases where the lesions were diffuse and more or less symmetrical throughout the whole lung substance. On the cut surface of the lungs in early cases of silicosis, the diffuse symmetrical distribution occurs in a minority of cases. More frequently the lesions are localised to restricted areas, where they may be moderately numerous or even numerous, but if the same number were spread over the whole lung symmetrically, they would be considered sparse. Less often a similar distribution may be met with in moderate and well-marked degrees.

Standards have been elaborated for the assessment of degrees of silicosis, where the islets are more or less symmetrical in distribution.

According to them, the word " sparse " is used when the distribution of the palpable islets on the cut surface of the lung is of the order of one silicotic islet in each square whose side is 5 centimetres in length; moderately numerous when the square has a side of 3 centimetres in length; numerous when the square has a side of

2 centimetres in length and very numerous when the square has a side of less than 2 centimetres in length.

From our definitions it is seen that the varying degrees of silicosis are not sharply defined, but merge gradually into one another.

Similar criteria are adopted for tuberculo-silicotic lesions.

Silicotic lesions, on the Rand, are pigmented and show up black, but not all pigmentation is silicotic. The presence of silicosis is determined not by pigmentation, but by the appreciation of a definite amount of palpable fibrosis in the lung substance.

In presilicotic conditions, there is accumulation and concentration of pigment in the root glands, but in them occur the first signs of fibrosis. At first the glands are slightly enlarged, slightly firm to the touch and pigmented by carbon. The pleura shows a definite increase in pigment, which tends to outline the periphery of the subjacent lobules, and the lung substance shows pigmentation in the form of discrete non-palpable islets.

As silicosis develops the glands are definitely enlarged, pigmented and firm to the touch. The subpleural pigmentation increases in amount and there is incipient plaque formation. The subpleural nodules have probably just reached the serous membrane and are seen as fine pin-point pearly white foci, surrounded by a ring of pigment. They are palpable but scarcely project above the surface. The serous membrane is still smooth and glistening. Sometimes there are patchy areas of pleural opacity, which are probably associated with infection. In the lung substance, sparse small islets of pigmentation become palpable. On section the lungs show moderately numerous discrete islets only a few of which are palpable. All islets are black in colour whether palpable or not.

With further advance of the disease, there is progressive fibrosis in the lymph glands, small subpleural plaques are formed, and the palpable islets in the lung parenchyma increase in size and in number so that a stage is reached when the lung section shows moderately numerous discrete islets of pigmentation, the majority of which are palpable and project above the cut surface of the lung. A slight amount of marginal emphysema may be noted and chronic bronchitis is present.

In the well-marked and very well-marked degrees of silicosis, the lungs may not be much increased in size, but show an increase in weight. Emphysema, particularly in the marginal regions and at the apex, is present as a more or less constant feature. There is also a chronic bronchitis with thickening of the walls of the larger bronchi. The root glands are enlarged, sometimes excessively so.

The pleura shows plaque formation to a marked degree, particularly at the apices and along the posterior borders of the lungs. The interlobar pleura is rarely affected. Opacities, patchy thickening and adhesions are usually present, though they are not purely silicotic in origin, but are the result of infection. The lungs on section show moderately numerous or numerous large palpable islets, black in colour but often with a greyish tinge in the centre. Massive areas of fibrosis may be present, in which, even on macroscopic examination, the individual islets may be recognised. The massive fibrosis is generally a little less dense in colour; the colour being rather a greyish black than pure black. In some cases, plaque formation has been noted on the diaphragmatic pleura, while in a relatively large number there is fibrosis of silicotic character in the gland groups in the posterior mediastinum, at the cardiac end of the stomach and in the upper part of the abdomen. In the case of the latter, they are found particularly around the pancreas and in the portal glands at the hilus of the liver. This extension is more commonly seen in tuberculo-silicosis, and we explain it as mainly retrograde spread along lymphatic channels, which communicate between the lung root glands, posterior mediastinal glands and the diaphragm; or more directly by way of the mediastinal pleura.

The macroscopic detection of tuberculo-silicosis in the early stages is attended with great difficulty. The islet is usually large, grey in colour and shows evidence of rapid growth or enlargement, though none of these factors is essentially characteristic of superimposed tuberculous infection. The large amount of fat contained in the islet is sufficient to explain the change in colour. The occurrence of numerous islets restricted to the sites of election for tuberculous infection may suggest that the lesions are tuberculo-silicotic. Probably such lesions are of infective type, but the paucity of suitable material for biological tests leaves the question still open.

In a well-marked case of tuberculo-silicosis, the root glands are grossly enlarged, of steel grey colour, sometimes with foci of caseation, sometimes of calcification. There are dense adhesions on the pleura with much scarring and patchy thickening associated with local emphysema. Plaque formation may be a prominent feature. Section of the lung shows numerous large grey islets, some with points of caseation. In localised parts numerous islets become confluent forming massive areas of fibrosis, a frequent site for which is just under the pleura, and towards the upper parts of the lobes of the lungs. These areas may show foci of caseation, evidence of breaking down and even actual cavity formation. Chronic bronchitis with great thickening of the bronchi is present. In a number of these cases there is no evidence of overt tuberculosis, but a proportion do show active tuberculosis with cavity formation and broncho-pneumonia.

Distribution of Lesions

The first lesion associated with silicosis appears in the root glands; next pleural involvement is seen, and cases may show plaque formation with enlarged glands with little evidence of the disease in the lung substance. In early cases the site of the lesions of the lung shows great variation. They may appear more or less symmetrically throughout both lungs or they may be more numerous towards the apices and in the posterior parts of the lungs. Occasionally they are localised in small areas; the localisation being most frequently seen at the apices.

In more advanced cases the nodules tend to be more symmetrically distributed. In some well-marked cases with numerous islets, the islets near the pleura are small, while those near the root are large and in the intermediate zone they are of medium size. This is not a constant feature, but is seen sufficiently frequently to be worthy of note.

Complications

The most important complication of silicosis is tuberculosis. If a silicotic patient does not die of some other disease or by accident, he will ultimately die of tuberculosis. Tuberculosis may appear early and give rise to tuberculo-silicosis, or may occur relatively late and produce obvious lesions of overt tuberculosis associated with excavation and tuberculous broncho-pneumonia. Sometimes the manifestation is a terminal miliary tuberculosis originating in a focus in some other organ. With tuberculosis there may be a chronic tuberculous pleurisy, showing a greatly thickened and adherent pleura. The lungs may be firmly anchored, particularly at the apices and this may play a part in the development of yet another complication—bronchiectasis.

There is bronchitis of a chronic type in all cases of well marked silicosis. The walls of the bronchi are much thickened and in some cases there is a diffuse dilatation giving rise to a fusiform type of bronchiectasis; occasionally a saccular bronchiectasis is seen, usually associated with chronic pleurisy. The evidence of bronchiectasis is sufficient to be noteworthy, but it is much less than might be expected in view of the constant bronchitis and chronic pleurisy.

Associated with the chronic bronchitis in silicosis or tuberculo-silicosis, there is gross emphysema. Large bullae are frequently seen along the margins and in the apical regions. We have met with one case of pneumothorax, due to rupture of a large bulla in a tuberculo-silicotic lung.

In certain cases when pneumonia affects a silicotic lung there may be non-resolution and organisation. This is seen in both lobar and broncho-pneumonia. In other cases, particularly in natives, gangrene is not an uncommon event.

Odema and congestion are frequently seen, but these are usually explained as terminal phenomena.

One other complication in the lung substance remains to be discussed — the incidence of primary carcinoma and its association with silicosis. We have met with seven cases of carcinoma in a series of European miners, all being carcinomata of bronchi. In a series of autopsies on Europeans carried out by us at the General Hospital, Johannesburg, only two cases of carcinoma of the lung have been observed. The number of cases is too small to permit of any accurate assessment of the place of silicosis as an etiological factor in carcinoma of the lung, but the possibility must be kept in view.

Changes associated with silicosis and tuberculo-silicosis may occur in organs apart from the lungs; particularly is this so with tuberculo-silicosis. In the glandular advance of tuberculo-silicosis we have seen the "caval" gland of the heart to be the seat of tuberculo-silicosis and the pericardium the seat of tuberculosis. As described by Shore [1], the caval gland is intrapericardial and drains into the lower tracheo-bronchial group. If the caval gland is involved in tuberculo-silicosis or tuberculosis it must be so by retrograde spread. The site of this gland and its relation to the tracheo-bronchial group may explain one mode of spread of tuberculosis from the lung to the pericardium.

As regards the heart itself, it is often stated that silicosis produces changes in the heart associated with hypertrophy. We have not been able to demonstrate this. Even in cases of gross fibrosis and emphysema, there has been little alteration in the weight of

---

[1] Shore: *Jour. Anat.*, April 1929, No. 63, p. 291.

the heart and little evidence of hypertrophy. When the cause of death is cardiac failure, emphysema and interstitial fibrosis are sufficient, as a rule, to account for the cardiac disability. Disease of the coronary vessels may also aggravate the condition.

Disease of the blood vessels is common on the Rand. It usually takes the form of atheroma and is not infrequently associated with calcification. This change may appear early in life. We have noted atheroma with calcification in cases as young as twenty-one years, and in females as well as males. Vascular disease is common amongst miners on the Rand, but does not appear to be more so than in members of the general population.

We have noted chronic nephritis in a proportion of cases, but in how far this is caused by vascular disease or by the silicotic process it is difficult to determine. Our impression, which is yet to be confirmed, is that the incidence of chronic nephritis is no greater in miners than in members of the general population.

With regard to the liver, we have not noted any preponderance of cirrhotic changes in silicotics. A few have shown haemochromatosis, but haemochromatosis is relatively common in both Europeans and natives in Johannesburg.

Apart from complicating tuberculosis of the lungs and mediastinum tuberculosis may be seen in other parts of the body. Normally it would appear that silicosis tends to localise the tuberculosis, but we have seen numbers of cases, in which there is evidence of metastatic foci occurring in other organs. At autopsy, such a case may show grossly enlarged tuberculo-silicotic root glands, extensive genito-urinary tuberculosis and a terminal miliary tuberculosis. This type of case is more commonly seen in natives but it also occurs in a small proportion of white miners. Similarly in cases where there is no evidence of overt tuberculosis in the lungs or root glands there may be tuberculomata in the brain and tuberculous meningitis.

Experimental Investigation of Tuberculous Infection in Silicosis without Overt Tuberculosis

As some authorities have suggested and maintained that silicosis is infected by tuberculosis in its earliest stages, it seemed advisable that the problem should be investigated from this point of view.

Not every lung sent for examination is suitable for this type of investigation. The specimens are rendered useless as a result of delay in transit and consequent putrefaction, or having been placed in fixative. Even in autopsies performed by ourselves many of the lungs showed post-mortem changes which rendered them useless for biological tests. Further, in a considerable number of cases the lungs were the seat of necrotic and caseous lesions, in which the tubercle bacillus was readily identified by ordinary bacteriological methods. These factors explain why so small a number of cases have been submitted to biological tests over a comparatively long period.

The material originally selected was from early cases of silicosis in which there was no suspicion of tuberculosis. The material for inoculation was selected from root glands, subpleural nodules and nodules from the substance of the lungs. Subsequently tissue was obtained from more advanced cases where tuberculo-silicosis was suspected. In one case only (J.R.B.) was there any sign of overt tuberculosis, but even in this case tissue was carefully selected from portions of the lung showing no active tuberculosis.

The silicotic lung, as is well known, is a " dirty " lung, but the tissues used for the tests were taken as aseptically as was possible in the circumstances. In the experiments the tissue was ground up both with and without the aid of sterile sand, in a minimal quantity of sterile saline. When thoroughly ground an emulsion was made in about 4 cc. of sterile saline and the whole inoculated into the left groin of a guinea-pig.

A few of the guinea-pigs died of septicaemia, but the majority lived sufficiently long for evidence of tuberculosis to develop.

An abstract made from the protocols of the various experiments is given in table I.

The experiments up to the present are few in number but are being continued when suitable material is made available.

From the few results recorded it is impossible to express any dogmatic opinion, but it is permissible to suggest certain conclusions.

The terms in the table, silicotic nodule, lung, small or large and black, indicate respectively: the material used, the site from which taken, size and colour and presumed absence of infection. The site also applies to root glands and tuberculo-silicotic area —and grey indicates presumed presence of infection but does not necessarily imply it.

With the black silicotic nodule, the results have been uniformly negative.

In the cases labelled tuberculo-silicotic as a result of naked-eye examination, a large percentage of positive results have been

TABLE I

Case	Degree of silicosis	Guinea-pig.	Date inoculated	Material inoculated	Date of death	Cause of death	Result
J.M.McD	Very occasional islet	1.A	20. 5.27	Silicotic nodules, lung. Small, black	30. 5.27	Enteritis	Negative
		1.B	20. 5.27	Silicotic nodules, lung. Small, black	25.11.27	Killed	Negative
A.J.R.	Very occasional islet	3.*a*	15. 6.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative
		3.*b*	15. 6.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative
H.P.B.	Very occasional islet	4.*a*	17. 6.27	Subpleural plaque large, grey	29. 7.27	Tuberculosis	Positive
		4.*b*	17. 6.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative
A.S.	Slight silicosis	2.*a*	27. 5.27	Subpleural irregular scars	25.11.27	Killed	Negative
		2.*b*	27. 5.27	Silicotic nodules, lung. Small, black	25.11.27	Killed	Negative
S.F.D.	Slight silicosis	7.*a*	19. 9.27	Subpleural plaques grey	11. 9.28	Killed	Negative
		7.*b*	19. 9.27	Silicotic nodules, lung. Small, black	5.10.27	Septicaemia	Negative
G.L.Q.	Slight silicosis	11.*a*	10. 9.28	Silicotic nodules, lung. Small, black	1. 2.29	Lobar pneumonia	Negative
		11.*b*	10. 9.28	Silicotic nodules, lung. Small, black	9. 1.29	Splenic abscess	Negative
W.A.S.	Slight silicosis	12.*a*	15. 9.28	Subpleural and deep large irregular foci	2.10.28	Pyaemia	Negative
		12.*b*	15. 9.28	Root glands tuberculo-silicotic	6. 3.29	Tuberculosis	Positive
W.W.	Moderate silicosis	6.*a*	8. 7.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative
		6.*b*	8. 7.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative

M.R.C.	Moderate silicosis	8.*a*	27.10.27	Silicotic nodules, lung. Small, black	11. 9.28	Killed	Negative
		8.*b*	27.10.27	Root glands soft, black	31.10.27	Septicaemia	Negative
L.W.P.	Moderate silicosis	9.*a*	27. 1.28	Silicotic nodules, lung. Moderate size, black	30. 1.28	Septicaemia	Negative
		9.*b*	27. 1.28	Large silicotic nodules. Tuberculo-silicotic	30. 1.28	Septicaemia	Negative
T.de B.	Moderate silicosis	16.*a*	31.12.28	Large area tuberculo-silicosis	20.11.29	Killed	Negative
		16.*b*	31.12.28	Large area tuberculo-silicosis	20.11.29	Killed	Negative
T.C.C.	Moderate silicosis	17.*a*	4. 1.29	Root glands tuberculo-silicotic	9. 1.29	Killed	Negative
		17.*b*	4. 1.29	Root glands tuberculo-silicotic	9. 1.29	Septicaemia	Negative
J.R.	Moderate silicosis	10.*a*	12. 4.28	Silicotic nodules, lung. Large, black	12. 7.29	Killed	Negative
		10.*b*	12. 4.28	Silicotic nodules, lung. Large, black	12. 7.29	Killed	Negative
C.J.S.	Moderate to marked silicosis	13.*a*	17.10.28	Tuberculo-silicotic nodules, lung	12. 7.29	Tuberculosis	Positive
		13.*b*	17.10.28	Tuberculo-silicotic nodules, lung	15.12.28	Enteritis	Negative
P.J.A.	Moderate to marked silicosis	14.*a*	30.11.28	Root glands tuberculo-silicotic	5. 7.29	Tuberculosis	Positive
		14.*b*	30.11.28	Nodules from lung tuberculo-silicotic	14. 6.29	Tuberculosis	Positive
V.J.D.	Moderate to marked silicosis	19.*a*	23. 4.29	Small root glands tuberculo-silicotic	20.11.29	Killed	Negative
		19.*b*	23. 4.29	Small root glands tuberculo-silicotic	20.11.29	Killed	Negative
C.M.J.	Well-marked silicosis	5.*a*	17. 6.27	Subpleural plaques black	18. 6.27	Septicaemia	Negative
		5.*b*	17. 6.27	Nodules from lung tuberculo-silicotic	5. 8.27	Tuberculosis	Positive
J.R.B.	Very well-marked silicosis	18.*a*	9. 4.29	Massive area tuberculo-silicotic	12. 7.29	Killed	Positive
		18.*b*	9. 4.29	Root glands tuberculo-silicotic	12. 7.29	Killed	Positive

obtained. These cases were, with two exceptions, in a state of marked tuberculo-silicosis. In one exception (H.P.B.) the tissue was taken from the subpleural region but was grey in colour, in the other (W.A.S.), though showing no tuberculo-silicosis of the lung itself, was from a gross tuberculo-silicotic gland.

If any conclusion can be drawn from the results of these experiments it would seem that they indicate that silicosis does exist and progress as a separate entity apart from tuberculosis. Further, as a result of our examination of the weights, the progress of the animals and the type and number of the tuberculosis lesions found, it would appear that an attenuated type of organism is associated with tuberculo-silicotic lesions.

Summary

The site of the silicotic lesions in the lungs appears to have an anatomical basis. This is related to the positions in which lymphoid tissue has been described.

The first evidence of change in the lung as a result of the inhalation of irritant dust is a " dry " bronchiolitis.

The manifestations of the silicotic process appear first in relationship to terminal bronchioles, vestibules and atria.

The silicotic process is a fibroblastic reaction followed by a dense fibrosis of nodular type, in which fat accumulation occurs in all stages and increases *pari passu* with the size of the nodule.

Massive fibrosis may result from the progress of uncomplicated fibrosis.

Infection modifies the silicotic process in the direction of excessive fibrosis.

The important infective factor is tuberculosis.

The macroscopic changes are usually seen, first in lymph glands then in pleura and lung substance.

The main complications are related to tuberculosis; others present are chronic bronchitis and emphysema.

Silicosis may exist and progress without superimposed tuberculous infection.

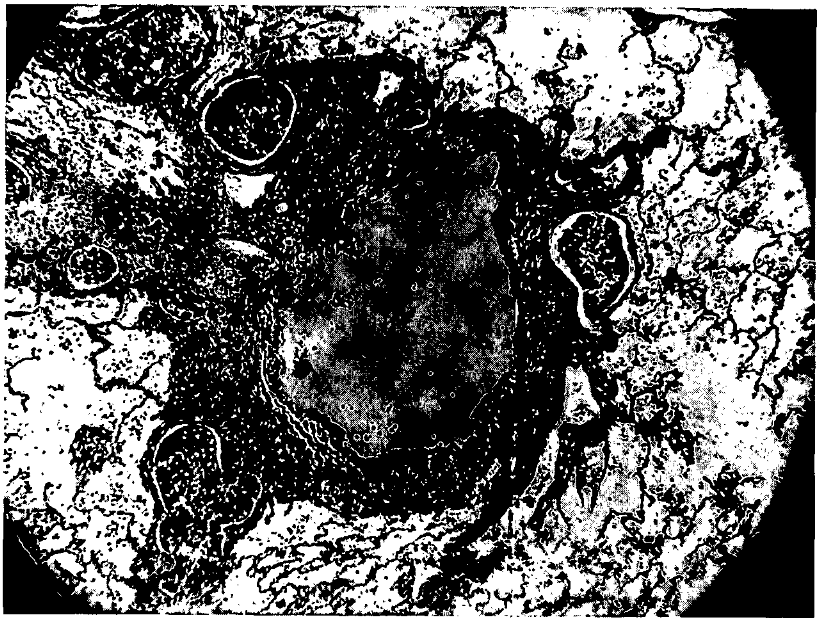


Fig. 1. — From a case of primary carcinoma of the lung with widespread lymphatic permeation. Section shows a bronchus in cross section, portions of septa, and surrounding air vesicles. The carcinoma-filled lymphatics are shown in the wall of the bronchus and in the septa, while the alveolar walls remain free from the growth.

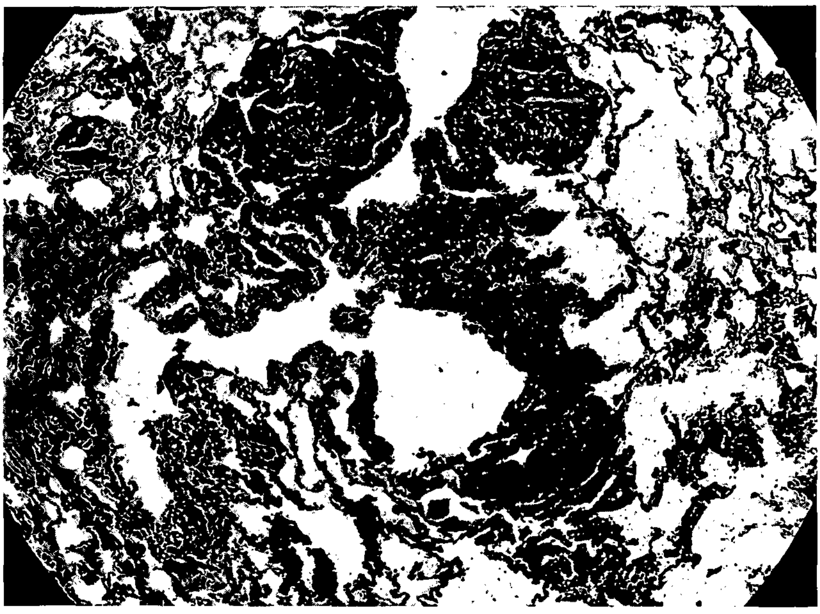


Fig. 2. — From a case of slight silicosis. This section shows the entrance to a lobule with several aggregations of pigmented cells. It is in these aggregations that the future silicotic nodule develops.

FIG. 3. — Dry bronchiolitis from a case of slight silicosis. Section of lung showing terminal bronchiole, vestibule, etc. Pigmented cells are present in the walls and almost complete denudation of the lining epithelium is shown. There is no evidence of exudate.

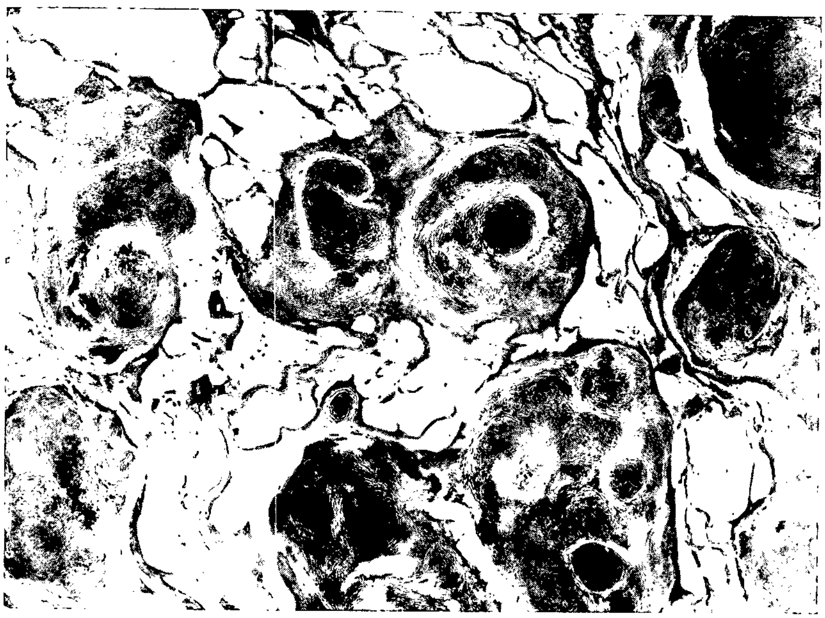


FIG. 4. — Very advanced silicosis. A small, well-defined, circular area of calcification is shown in the centre of one of the nodules. This type of change is also seen in nodules of less advanced cases.

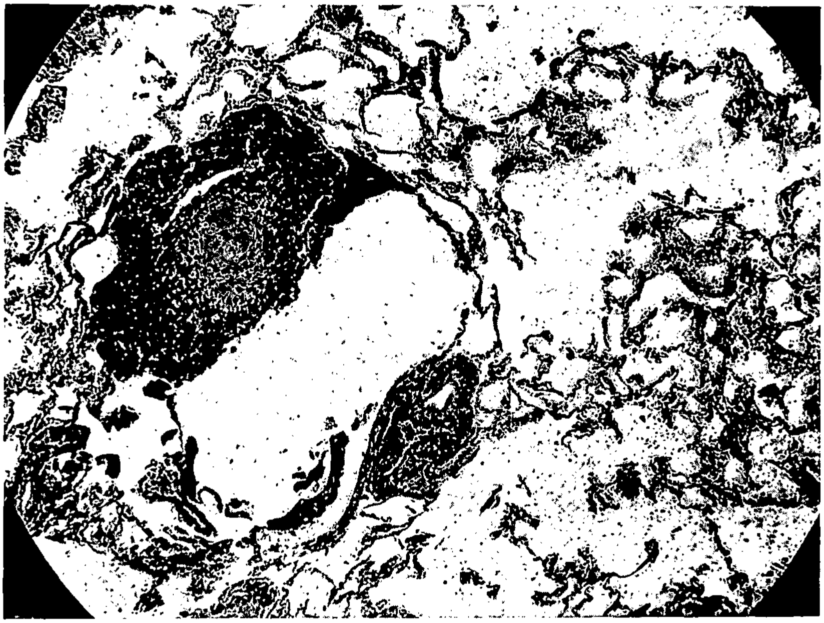


Fig. 5. — From a case of early silicosis. Section shows an aggregation of pigmented cells in the wall of a bronchiole. In the centre of the pigmented mass *the early, cellular, fibroblastic reaction is seen.*

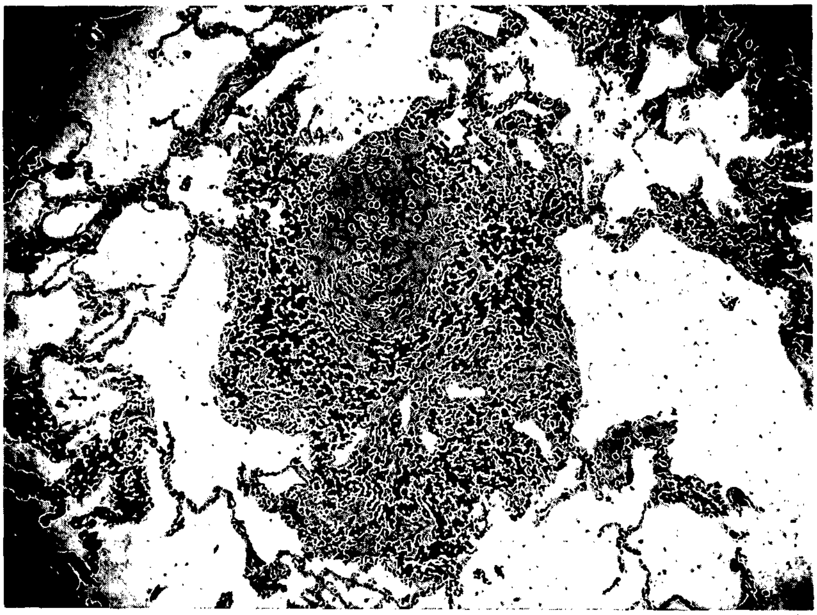


Fig. 6. — Early simple silicosis. Higher power section of pigment cell aggregation, with slightly more advanced central fibroblastic reaction.

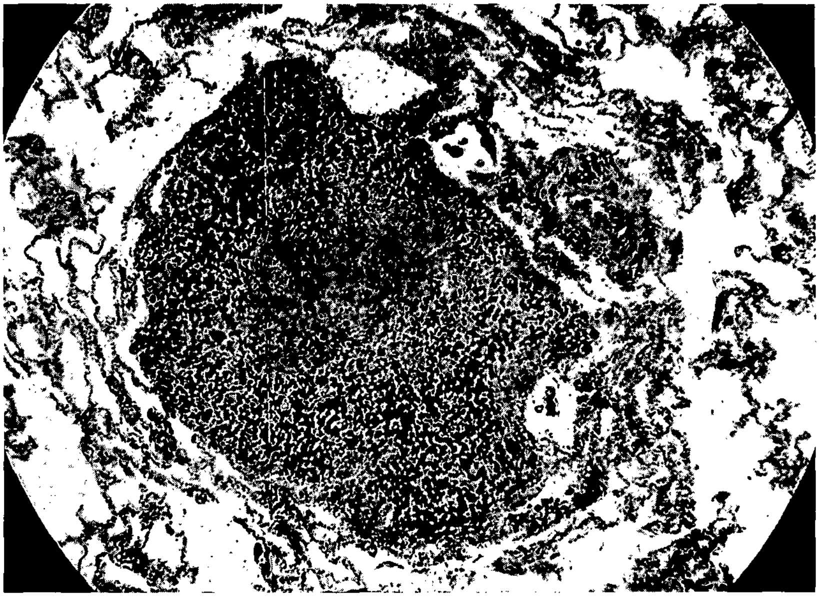


FIG. 7. — Slight silicosis. Infective type. A pigment cell aggregation is shown with central fibroblastic change. This is the cellular type resembling granulation tissue. Blood vessels are absent. In the later stages, when fibrosis has taken place, breaking down of the central mass occurs early.

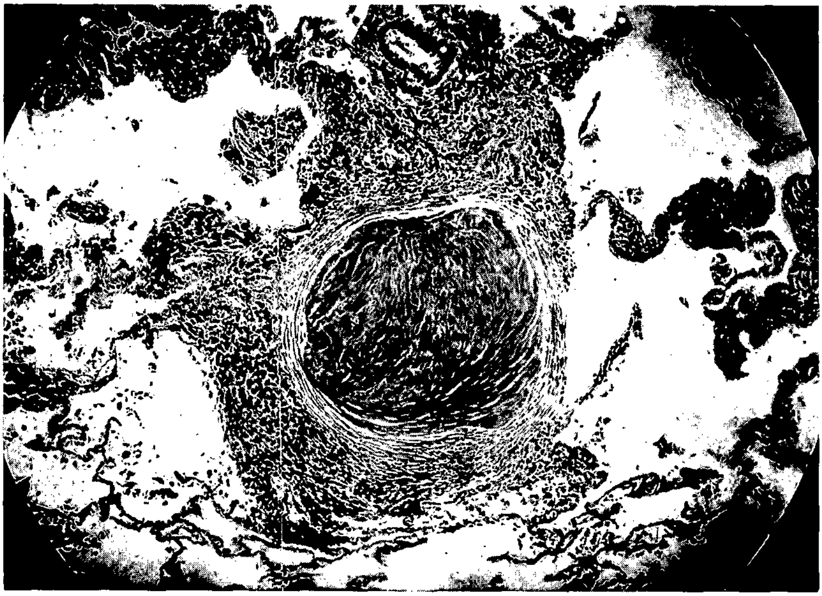


FIG. 8. — Early simple silicosis. Section shows a fibrotic nodule situated in the region of a terminal bronchiole. It consists of a mass of irregularly arranged, well formed fibrous tissue in the centre, surrounded in turn by concentric laminae of fibrous tissue, fibroblasts and pigmented cells. Dust cells and almost the whole of the carbon pigment have disappeared from the fibrous tissue zone. There is no evidence of breaking down.

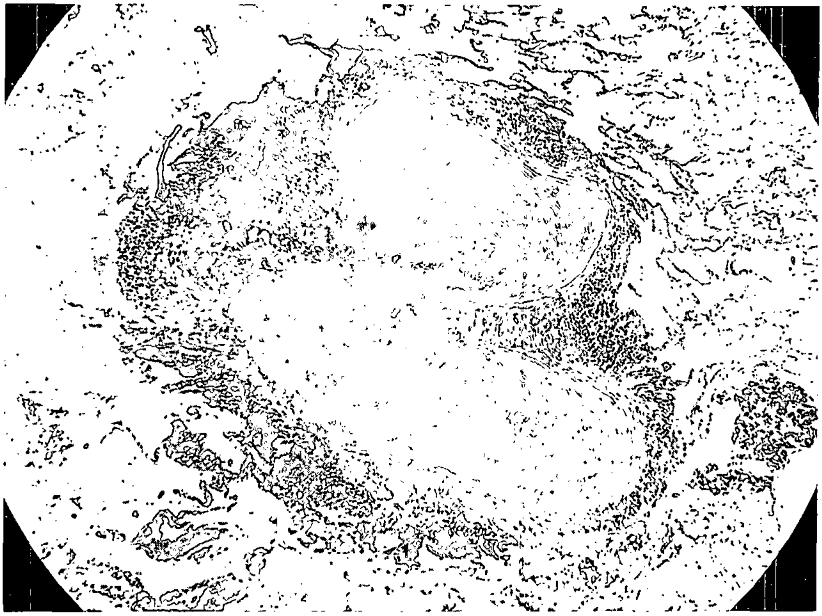


Fig. 9. — Early simple silicosis. A composite nodule is shown. It consists of at least three centres of origin. Each centre represents the original site of a mass of pigmented cells in relationship to a bronchiole, vestibule or atrium.

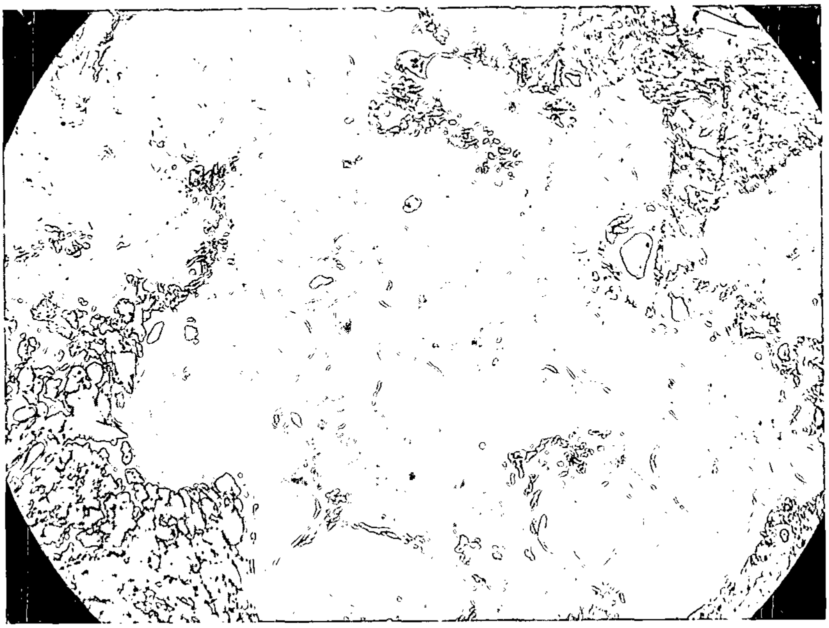


Fig. 10. — Well-marked silicosis. Massive area of single and large composite islets. The islets are contiguous, causing compression and collapse of the intervening lung tissue. The bronchioles are probably occluded in this type of change. The larger blood vessels appear to be unaffected. All these nodules are composed of dense fibrous tissue and show no breaking down or other sign of infection.

FIG. 11. — Well-marked silicosis. Two large, well-developed subpleural nodules are shown in this section. Where the nodules approach the surface no pigmented cells are seen. As a rule the subpleural islet is more flattened, it projects above the surface and a thicker layer of laminated fibrosis is seen just under the pleura.

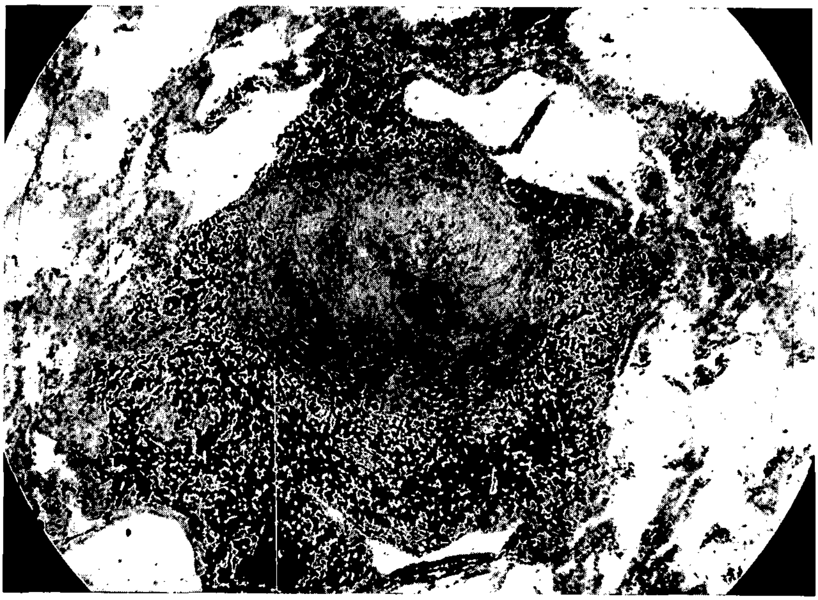


FIG. 12. — Early silicosis. Infective type. This nodule consists of a central mass of fibrous tissue, which shows a tendency to break down. This is surrounded by a very cellular fibroblastic layer and an outer pigment cell zone. In a later stage the central portion will become quite necrotic without any of the usual signs of tuberculosis.

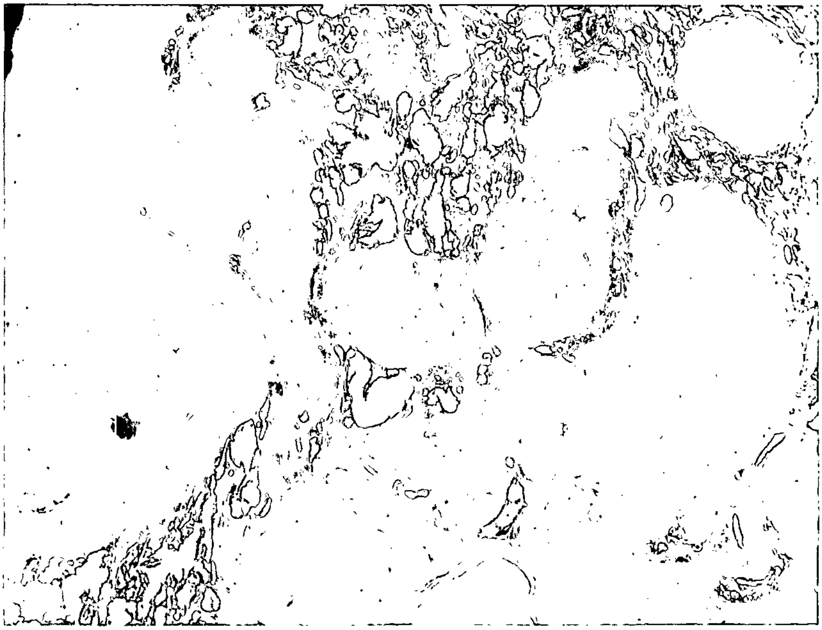


Fig. 13. — Advanced tuberculo-silicosis. This section shows a second type of massive fibrosis. It consists of numerous nodules, many of which have coalesced. In the larger masses there is evidence of central caseation. The usual signs of tuberculosis (follicle formation and giant cells) are absent. Material such as is shown here usually gives a positive biological test for tuberculosis.

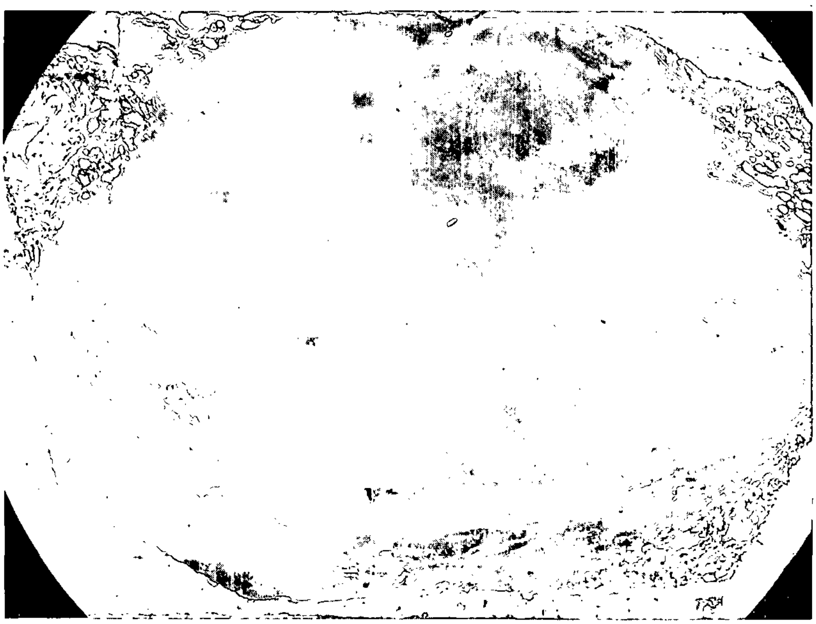


Fig. 14. — Advanced tuberculo-silicosis. This section shows a massive area of tuberculo-silicosis. The nodules have coalesced and the whole structure has become converted into a pigmented, necrotic mass. Tubercle follicles and giant cell formations are absent. This type of lesion also gives a positive biological test for tuberculosis.

THE CLINICAL PATHOLOGY, RADIOLOGY AND SYMPTOMATOLOGY OF SILICOSIS

TWO PAPERS

INTRODUCTORY

The object of these two papers is to present a concrete account of silicosis *as met with in South Africa*, from the several aspects of its clinical pathology, radiology and symptomatology, and particularly from the aspect of the correlation which has been found to exist between the results of these different methods of investigation of the disease, as an aid to formulation of precise criteria for its practical diagnosis.

Such precise criteria are of much practical importance, since silicosis has become in many countries the subject of a legal system of compensation as an " occupational disease ", but their formulation is a matter of some difficulty, inasmuch as the silicotic process develops from minute beginnings extending over a considerable period of time, during which health and functional activity are in no way disturbed. It is therefore of practical importance to determine at what point that process produces results which can be regarded as a condition of definite " disease ". The diagnosis in such circumstances must be " pragmatic " rather than simply academic.

It is impossible, in our experience, to deduce a practical standard of diagnosis from accounts of the disease furnished separately by the pathologist, the radiologist, and the clinician. Clinical examination is obviously an essential factor in the decision in any individual case, since it provides us with important information, which we cannot otherwise obtain, regarding the general and local condition of the patient, the degree of incapacitation, if any, which exists, and the presence or absence of complication by active infection, or by disease of other organs. But in the case of such a disease as silicosis, in which, in respect of the diagnosis of the earliest stages of the condition, clinical evidence is in many cases inconclusive and may be misleading, such evidence taken by itself is an insufficient guide. The standard of diagnosis which we seek, while in no way ignoring the clinical factor, should rest as far as possible upon an objectively demonstrable basis. Only so can we reach an approximately uniform standard and one which can be described in terms which are generally intelligible to other people.

Physical measurements of respiratory function, such as vital capacity, respiratory force, etc., give results which are objective so far as they go, but they show such considerable individual variations, and are so readily modifiable by subjective factors, including the psychical attitude towards the test of the person examined, that they do not in themselves supply a sufficiently precise guide.

There remain in the living subject radioscopy and radiography, and in the last resort the pathological condition found after death. Radiography, again, has its limitations, since on the one hand not all forms of pulmonary fibrosis which it reveals, even in miners, are of silicotic origin, and on the other hand certain types of radiograph which do not show unequivocally "specific" signs of silicosis, may yet in certain circumstances be legitimately regarded as affording evidence of the presence of a silicotic factor in the case. One can only obtain full value from the radiograph when one is able to interpret it in the light of experience derived from extensive pathological observation. Only when one has been able to *correlate* the results of pathological observation in a large number of cases with radiographs taken from the chests of the same individuals shortly before death, and with the results of clinical examination made during life, is one in a position to obtain the accurate knowledge which is required to formulate a reliable general standard of diagnosis. The very extensive material at the command of the Miners' Phthisis Medical Bureau in each of the three directions mentioned has enabled it to effect this triple correlation in a large series of cases. The systematic "periodical" examination of working miners which forms one of its main functions has provided it also with the opportunity of observing, in many hundreds of cases, the first appearance of the earliest clinical and radiographic signs of silicosis, and to follow their subsequent development.

An accurate standard of diagnosis in silicosis should rest on the triple correlation described. But, when this has been effected, it will be found that, when interpreted in the light of this correlation, *a radiograph which is of high technical quality, and which is taken instantaneously, forms the most reliable single diagnostic criterion which we possess.* It provides us with a general basis of diagnosis which is at once objective and trustworthy, in so far that it narrows down the issue by the exclusion of cases which do not show certain determined characteristics. But it is never the only factor in a decision. The final adjudication in any individual case must always incorporate the additional evidence supplied by expert clinical examination, which indeed is frequently the deciding factor, particularly in borderland cases. It is assumed also, as a matter of course, that the previous industrial and medical history of the individual has been thoroughly investigated. In the light of what has been said it will, we think, be found convenient to deal with the subject of our discussion under two main headings. It is proposed, therefore, first to discuss briefly some aspects of the clinical pathology of silicosis, considered particularly in relation to pathological diagnosis. This will provide us with a summary view of the general character and course of the disease. Thereafter the clinical and radiographic diagnosis of silicosis will be dealt with.

The two papers submitted are the result of team work. Drs. A. Sutherland Strachan and F. W. Simson, of the pathological staff of the South African Institute for Medical Research, who conduct the routine pathological work for the Bureau, have taken a large part in the preparation of the first paper, which embodies several important new observations made by them upon the pathology of the disease. Dr. Simson is also responsible for the illustrations representing the pathology of simple and infective silicosis (see figs. 1 to 10). Dr. W. Steuart, Radiologist to the Bureau, has collaborated in the preparation of the sections relating to radiography in the second paper. Members of the Bureau have also rendered valuable co-operation, particularly Drs. E. H. Phillips and S. W. Verster in recording and classifying the series of over 350 "correlation " cases, Dr. D. A. Ogilvie in investigating the causes of death in cases of silicosis, and Dr. J. G. McMenamin in recording the distribution of the different varieties and degrees of fibrosis, as indicated by the radiograph, amongst initial examinees and working miners. Mr. J. H. Dowds, of the University of the Witwatersrand, conducted the series of physical tests on non-silicotic and silicotic miners, the general results of which appear in the second paper. The series of prints illustrating radiographic appearances in silicosis (films 1 to 22) have been reproduced by Kodak, Ltd., Johannesburg, from negatives taken at the Bureau. The Chairman of the Bureau (Dr. L. G. Irvine) is responsible for the actual form of both papers, which with several modifications follow closely and in parts verbally the lines of a communication on the subject contributed by him to the meeting of the Permanent International Committee for the Study of Occupational Diseases held at Lyons in 1929 [1].

One may add that the conclusions set out are based almost wholly upon the practical experience gained by the writers from the material made available from the work of the Medical Bureau. They will be found, however, to be in substantial agreement with the presentation of the subject in the paper on " Silicosis on the Witwatersrand ", by Watt, Irvine, Steuart and Pratt Johnson, published as an appendix to the General Report of the Miners' Prevention Committee in 1916 [2].

Since in these papers we are dealing solely with South African silicosis, the references made to the work of other writers have been practically confined to the local literature of the subject.

The figures and films mentioned in the two papers are given after page 294.

I. — THE CLINICAL PATHOLOGY OF SILICOSIS

BY L. G. IRVINE, M.A., M.D., C.M., B.SC. (PUB. H.) (EDIN.), CHAIRMAN, MINERS' PHTHISIS MEDICAL BUREAU; F. W. SIMSON, M.B., CH.B. (EDIN.), PATHOLOGIST, SOUTH AFRICAN INSTITUTE FOR MEDICAL RESEARCH; AND A. SUTHERLAND STRACHAN, M.A., B.SC., M.D. (GLASGOW), PATHOLOGIST, SOUTH AFRICAN INSTITUTE FOR MEDICAL RESEARCH

There are two factors which are predominant in the course of cases of silicosis as we meet them in South Africa — silica dust and tuberculous infection. Other factors, such as intercurrent non-tuberculous infections, may modify the course of the disease, and may indeed not infrequently be the immediate cause of death

[1] L. G. IRVINE: " The Diagnosis of Silicosis as an Occupational Disease. " *Rapports; Réunion de la Commission Internationale Permanente pour l'étude des Maladies professionnelles*, p. 43. Lyons, 1929.

[2] A. H. WATT, L. G. IRVINE, J. PRATT JOHNSON and W. STEUART: " Silicosis (' Miners' Phthisis ') on the Witwatersrand. " *General Report of the Miners' Phthisis Prevention Committee*, p. 81. Pretoria, 1916.

in silicotic miners as in other people. But apart from this circumstance, the predominant factors are those just named. The typical history of an average case is that it begins as a dust fibrosis and ends as a dust phthisis. Without dust there would obviously be no silicosis, but, without the predisposition to tuberculous infection which the presence of silica dust in the lung induces, silicosis would not be the gravely disabling and fatal disease which, in its later stages, it becomes.

One uses the term " simple silicosis " to describe a condition of fibrosis of the lungs which is produced by the long continued inhalation of siliceous dust, and its subsequent entry into and arrest within the lung, and which is unaccompanied by overt signs of active tuberculous infection. This is the condition of the immense majority of cases in the earliest detectable stage of the disease, at which it first becomes notifiable, and at which also by far the greater number of the men affected cease work underground.

The significance of such a case, however, is not what it is at the moment, but what it may become. At the moment the affected man is, generally speaking, quite in good health and has at the most only a comparatively slight impairment of working capacity. But in the majority of cases the disease tends sooner or later to advance. There are wide individual variations. Some may remain stationary practically indefinitely. Others may remain stationary for long periods, and may then begin to show signs of advance. In others again the progress of the disease is rapid from the first. But, although these individual variations occur, the general tendency to advance is on the whole fairly uniform. And, although an uncomplicated silicosis may, and does, in itself progress, and will do so up to a point even if the man affected ceases to work underground, the most important factor which accounts for the progressive tendency manifest in most cases of the disease is *infection*, and particularly tuberculous infection. The " simple silicosis " tends in most cases to become an " infective silicosis ". The terminal stage of the disease, if it be reached, is one of obvious active tuberculosis in the silicotic lung. But not all cases reach that stage.

In the present paper an attempt is made to present a brief review of the respective roles played by the factor of dust and the factor of infection in the course of the disease, considered particularly in their bearing on the practical question of diagnosis, and of the differentiation of the several " stages " of the disease of which a system of legal compensation must take account.

THE DUST FACTOR IN SILICOSIS — THE ORIGIN OF THE SILICOSIS PROCESS

The genesis of the silicotic process has been repeatedly described [1], and, although variations may exist in the precise interpretation of the phenomena observed, there is substantial agreement as to the general facts. By "the silicotic process" one means the fibrotic changes produced in the lungs by the repeated inhalation over long periods of a "phthisis-producing" dust which contains free silica, in quantities greater than can be successfully dealt with by the physiological protective mechanisms of the respiratory organs.

Dr. J. McCrae [2] and later Drs. Watkins-Pitchford and J. Moir [3] showed many years ago that it is only the minutest particles which gain entry into the lungs, and this observation is in conformity with the fact that their mode of entry is by phagocytosis.

Even if the expulsive functions of the epithelium and musculature of the air-passages remain intact, dust particles may reach the alveoli and some may be taken up into the lungs. The extent to which this will happen will depend upon the intensity of the exposure to dust and upon the physiological efficiency of the defensive structures and function of the respiratory passages and alveoli.

But one effect of the repeated inhalation of abnormal quantities of silica dust is to produce in time a dry bronchitis and bronchiolitis, with eventually a greater or less amount of denudation of the epithelium particularly of the bronchioles. This condition may be found in lungs which have undergone long-standing and repeated exposure to dust, even in cases which do not yet show definite signs of silicosis. It must eventually produce a situation which

---

[1] A. H. WATT, L. G. IRVINE, J. PRATT JOHNSON and W. STEUART, *op. cit.*
W. WATKINS-PITCHFORD: "The Industrial Diseases of South Africa." *S. A. Medical Record*, 1914, Vol. XII, No. 3, p. 33.
—— "The Gross Characters of the Silicotic Lung." *Med. Jour. of S. Africa*, 1915, Vol. X, No. 10, p. 167.
A. MAVROGORDATO: *Studies in Experimental Silicosis and other Pneumonoconioses*. S.A. Inst. Med. Res. Publn. XV. 1922.
—— *Contributions to the Study of Miners' Phthisis*. S.A. Inst. Med. Res. Publn. XIX, 1926.

[2] J. MCCRAE: *The Ash of Silicotic Lungs*. S.A. Inst. Med. Res. Publn. III, 1913.

[3] W. WATKINS-PITCHFORD and J. MOIR: *The Nature of the Doubly Refracting Particles seen in Microscopic Sections of Silicotic Lungs*. S.A. Inst. Med. Res. Publn. VIII, 1916.

directly and increasingly facilitates the entry of dust into the lungs. *It appears to be an important factor in the original development of definite silicotic changes in the lung substance*, and to be an important factor also in the further development of the latter.

When silica dust enters the alveoli it does so in company with fine pigmented carbonaceous particles, derived chiefly from the smoke of lamps and candles. The latter are taken up into the lungs by the same agency and follow the same distribution as the silica dust, and thus give to the lesions produced by the latter their characteristic pigmented appearance. *But mere excess of pigmentation in a lung does not necessarily spell silicosis*, and, on the other hand, in mines in which there is little smoke there may be silicosis without any marked excess of pigmentation. In the cases we see on the Witwatersrand the silicotic lesions are always pigmented. But the relation is accidental, not essential, and the amount of pigmentation which is present does not in itself afford a measure of the degree of silicosis which may exist.

In the alveoli the dust and pigment particles are taken up by the " alveolar phagocytes " or " dust cells ". Some of these are expelled by way of the air passages and are expectorated; some, and in time many, enter the lymphatic channels of the lung. The " dust-cells " tend thereafter to follow the course of the lymph channels by way of the peribronchial, perivascular and septal lymphatics within the lung, and of the rich sub-pleural lymph plexus, to the lymph glands at the root of the organ. In all of these situations many " dust cells " with their loads of dust and pigment undergo arrest, and the most important seats of arrest are the sites in which small aggregations of lymphoid tissue have been shown to exist in the normal lung[1] in relation particularly to the peribronchiolar and perivascular lymphatics. The site of election for arrest in the lung substance appears to be at the entrance to the lobule; in the subpleural region it is at the points of junction of the lymph systems of the lungs and pleurae. At these sites the dust cells become aggregated in small discrete " clumps ", and these points of clumping become the eventual seats of origin of the fibroid " nodules " which form so characteristic a feature of the developed disease. Given continued exposure to dust, the process is a cumulative process.

Observation of many lungs in the earliest stages of the silicotic

---

[1] Cf. especially W. S. Miller: " Distribution of Lymphoid Tissue in the Lung. " *Anatomical Record*, 1911, Vol. V.

process has shown that fibrosis with associated pigmentation begins first in the lymph glands at the root of the lung. There appears next, most commonly, some increase in pigmentation in the visceral pleurae, with, in parts, some irregular areas of slight opacity, or of more definite thickening, indicative of concurrent infection, past or present. The pigmentary changes in the pleurae are usually at this stage of the process definitely in advance of the similar changes which in turn become apparent in the lung substance.

The latter show on the cut surface of the organ as small discrete pigmented islands, *unassociated as yet with visible or palpable fibrosis.* Microscopic examination shows that the pigment is almost wholly aggregated in the sites of clumping already described as being associated with small aggregations of lymphoid tissue, and in some of these small rounded foci of fibro-blastic reaction may be observed. The alveoli are not affected; the septa show no appreciable thickening; the lungs retain their normal resilience on handling. But there is some amount of associated bronchiolitis and bronchitis. These changes precede the appearance of definite palpable " nodulation "; at the most a very occasional small palpable islet may be detected here and there, under the pleurae, or in the lung substance.

Although the pathological development in the silicotic process is continuous and cumulative from the earliest minute beginnings of fibrosis, the changes produced up to this point, when considered from the standpoint of their effect upon respiratory function, do not constitute a definite degree of " silicosis ". They tend, however, to produce a characteristic modification of the radiographic appearances, described in the Bureau's terminology as a " commencing generalised fibrosis " (cf. film 6). It is suggested that this is in some and probably in large measure associated with the accompanying bronchitis and bronchiolitis, but it may be in part also due to a fine fibrosis originating around the peribronchial and perivascular lymphatics.

The microphotograph shown in fig. 5 illustrates the condition present.

The Dust Factor in Silicosis — " Simple Silicosis "

If one employs the term " simple silicosis " to designate a condition of silicosis which is unaccompanied by a clinically detectable or " overt " tuberculosis, one may say that, viewed from the practical standpoint of effect upon respiratory function, *the develop-*

ment of an appreciable degree of " simple " silicosis coincides with the appearance of some amount of palpable miliary " nodulation " under the pleurae and in the lung substance. We shall expand this statement in a moment.

This condition of " nodulation " supplies a general and readily recognisable standard of diagnosis, and is the distinctive feature of the disease, particularly in its earlier stages. The individual silicotic " nodules " develop as a reactive fibrosis in the sites of the minute " clumps " of " dust cells ", of which we have spoken (cf. fig. 6). They form irregular " beadings " along the course of lymphatic channels, particularly, as has been said, at the entry to the lobule, and in the subpleural area.

As the process of fibrosis increases, the individual nodules coincidently increase in size and number, so that they eventually become distributed more or less widely throughout the lung substance, although they show a predilection first and throughout for its upper and posterior portions, and are always less obvious in the more freely movable lower and marginal regions of the lung. Under the pleural surface they have a similar general distribution. The subpleural nodule is typically a firm, somewhat flattened " plaque ". In the lung substance the individual nodule shows as a dense, black, rounded structure, which projects slightly from the cut surface, and is definitely palpable as firmer than the surrounding lung tissue, from which it is sharply marked off. The microscopic structure of the developed nodule is characteristic. In the centre is a core of typically acellular fibrosis, in which the fibres are disposed irregularly, with dust and pigment particles, derived from disintegrated dust cells, lying apparently free between the meshes. Around the central area are concentric layers of fibres, in the outermost of which the cellular elements are for the most part apparent. The peripheral zone is still unorganised, and is crowded with " dust cells " laden with dust and pigment.

The growth of the nodule is snowball fashion, by concentric additions at the periphery. At first of " small " size (up to 2 mm. in diameter), the individual nodule may, as the disease advances, reach a size of 5 mm. or thereabouts; one would call the latter type of nodule " large ".

The silicotic " nodule " forms so conspicuous a feature of silicosis that for the purpose of rapid diagnosis one may describe the stage or " degree " of an uncomplicated or " simple " silicosis in terms of the number, size and density of the nodular elements seen upon the cut surface of the lungs, when these organs are laid open by the knife. The Medical Bureau, for the practical medico-legal purposes of its work, which demands the classification of the disease into definite " stages ", is accustomed to distinguish four " degrees " of simple silicosis — " slight ", " moderate ", " well-marked " and " very well-marked ". And, speaking in general terms, it may be said that, in the two former the nodules are " small " and respectively " sparse " or " moderately numerous "; and that in the two latter they are " medium " to " large " in size, and " numerous " or " very numerous ".

The distinctive characteristic of the silicotic process is that it begins as a fibrosis which affects independently, simultaneously or in succession, many different points in the lungs, so that *the developed disease is typically a generalised disease.* And this character of generalised change is equally apparent in the radiograph and in the complex of physical signs and symptoms which distinguish the condition. There are exceptions, however, to this statement, to which we shall presently refer.

The Macroscopic Appearances in " Simple Silicosis "

It will be sufficient, from the aspect of pathological diagnosis, to describe, in illustration of these general observations, the macroscopic appearances of a typical case of " simple " or uncomplicated silicosis of a " moderate " degree, it being understood that by " uncomplicated " one means a case of silicosis in which there are no obvious signs of active tuberculosis or other infection. In examining the lungs one should look for evidence of fibrosis in the three sites mentioned — in the root glands, in the pleurae, and in the lung substance.

In such a case the root glands will be found to be somewhat enlarged, deeply pigmented, and firmer to the touch than is normal. The surfaces of the visceral pleurae are for the most part smooth and glistening. They show, however, a moderate or even considerable excess of pigmentation, in part merely in the form of a marbled outlining of the underlying lobules of the lung, in part as a more diffuse pigmentation, with areas of slight thickening, affecting particularly the upper half of the organ. Where areas of well-defined thickening are present an infective origin of these may be assumed. The inner, interlobar and diaphragmatic surfaces are less affected. In association with these changes there will be found scattered over the areas which show more marked pigmentary change a moderate number of small, sub-pleural nodules or "plaques", which give the appearance and "feel" of a fine mammilation.

The cut surfaces of the lung itself will also show excess of pigmentation in the form of moderately numerous "small", discrete pigmented islands, and a considerable proportion of these insular areas will be found to be the sites of well-defined, "small", firm, rounded and definitely palpable nodules of silicotic type. Except for this, the normal resilience of the lungs on handling is retained. The general appearance is thus one of a more or less generalised "small" miliary nodulation of moderate amount. The general character of the condition present is indicated in figs. 1 and 7. It is also very well brought out in the radiograph of such a case (cf. film 9). In the radiograph both lung fields will be seen to have, throughout, a characteristic "mottled" appearance, produced for the most part by the shadows thrown by individual "small" nodules. This characteristic discrete "mottling" is the one "specific" radiographic sign of silicosis. At this stage of silicosis, microscopic examination shows that, except perhaps in the immediate neighbourhood of the nodules, there is no evidence of alveolar fibrosis. Nor is there evidence of any definite thickening of the interlobular septa or the trabeculae of the lung. A slight degree of emphysema may be present. Apart from the effects of the coincident bronchitis and bronchiolitis, any interference with respiratory function which may exist would appear to be due to some slight limitation of the expansibility of the lungs; but, judged by measurements of vital capacity, this is not on the average at all marked.

This is the general picture. There is, however, a type of case in which the presence from the outset of an infective element in the process of silicotic fibrosis is strongly suggested.

It is not uncommon, for example, to find that in some cases the pigmented fibrotic lesions take the form of more massive and uniform, although still moderate, areas of fibrosis, or of a cluster of unusually large irregular nodules, confined or practically confined to the apical regions of the lungs, and associated with a well-marked thickening of the overlying pleura. The remaining portions of the lung show no obvious silicotic lesions.

Or again, we may find nodules of this larger atypical form, scattered or clustered here and there, in lungs whose general condition is that of the more uniformly distributed miliary nodulation of a typical silicosis.

These atypical nodules do not conform to the description previously given. They are larger and more irregular in shape than the typical silicotic nodule, generally a greyish black in colour, and stippled perhaps with points of necrosis and sometimes of caseous or calcareous change. Their minute structure differs also from that of the typical silicotic nodule. Although portions of these larger nodular formations may show the typical concentric arrangement of fibres, in other portions the fibres may be found to be distributed in irregular zones enclosing focal areas of necrosis. One or two of the root glands corresponding to the areas in which these irregular nodules are present may be found to show a similar appearance.

One has for long held the view that in most cases lesions of this atypical character are indicative of past or present infection and that many at least are the product of a localised low-grade tuberculous infection, occurring during the development of the silicotic lesions, and this is the more probable inasmuch as dust and the tubercle bacillus are both phagocyted by the same type of cell. Where caseation or focal necrosis is present the association of an infective element is clear. Further, a series of animal inoculation experiments recently carried out by two of us (F. W. Simson and A. S. Strachan) with material derived from lesions of this type, which showed no obvious evidence of tuberculous infection, has demonstrated its presence in a considerable number of instances.

One concludes therefore that in many cases of clinically "simple silicosis", even at its earliest detectable stage, an element of low grade and latent tuberculous infection may already be present in association with certain of the "silicotic" lesions. And the circumstances suggest that in such cases the infection is at least frequently an infection by inhalation [1].

Just as one finds in a precedent or coincident bronchitis and bronchiolitis a determining factor in the original development of a definite condition of silicosis in the lung substance, so here one appears to find at least one determining factor in the advance from a clinically "simple" to a clinically "infective" silicosis, which characterises the further history of a majority of cases of the disease.

The same qualifications regarding the possible presence of limited foci of low-grade infection applies equally and usually in greater measure to the later stages of clinically "simple silicosis".

[1] A. Mavrogordato: "Contributions to the Study of Miners' Phthisis", *op. cit.*

The more marked degrees of " simple silicosis " show more marked changes of the same general type as those described above. The nodules in the lung substance are for the most part larger and usually more abundant, and microscopical examination shows that many are of composite structure, resulting from the fusion of several originally more or less distinct small nodular formations. The pleurae also show more marked nodulation and more definite thickening. In the more advanced stages bronchitis is well marked and the bronchi are obviously thickened. So, too, may be the septa and trabeculae, but this condition is never gross. Growth of the nodules, particularly where they are closely aggregated, produces some obliteration of alveoli, but apart from this, alveolar fibrosis is not an obvious feature except in areas where infection is present. There is always in the later stages some amount of emphysema. Figs. 2 and 8 show the condition in " well-marked ", and " very well-marked " cases, and this is also well portrayed by the radiograph (films 11 and 13).

The Infective Factor in Silicosis — " Infective Silicosis "

Silicotic lungs, like other lungs, may become at any time the seat of a complicating infection. This is the more likely because, as Dr. Mavrogordato is fond of saying, " the silicotic lung is generally a dirty lung ". The accompanying bronchitis in itself makes it so. Evidence of infection may be obvious — lobar pneumonia may be found, or influenzal pneumonia, or an acute caseating tuberculosis, or a terminal miliary tuberculosis, each presenting its usual distinctive pathological features.

More chronic or less massive acute infections tend, however, to produce somewhat atypical results in a silicotic lung; *they tend to stimulate the development of fibrosis in the area affected by them.* This is particularly the case with low-grade tuberculous infections, although the tendency is not confined to such infections alone.

It is common knowledge that a lung affected by silicosis is peculiarly prone to become infected with tuberculosis. Several circumstances may contribute to this predisposition. First, there is the point emphasised by Mavrogordato [1] that the humid, dust-laden atmosphere of a mine forms a vehicle which directly facilitates the entry of the tubercle bacillus into the lung. We have already stated that pathological observation has led one to the belief that,

[1] *Ibid.*

in many cases of clinically apparently uncomplicated silicosis there is evidence of an early association of an element of low-grade tuberculous infection with certain of the developing silicotic lesions, and the distribution of these " infective " lesions is frequently very suggestive of an inhalation infection. Active tuberculosis may develop later on from such original foci, or may be due to further infection from other sources within or outside the lung.

A second circumstance is that the sites of silicotic lesions provide possible points of arrest of bacteria in the lymphatic system of the lung.

And finally there is to be considered the view which has recently been advanced on experimental evidence by Gye and Kettle, namely, that finely divided silica acts as a soluble protoplasmic poison, particularly to endothelial cells, and has in consequence a specific effect in determining the selection by a tuberculous infection of sites where silica is aggregated [1]. One may regard all of these factors as contributory to the predisposition in question.

As we have said, typical acute tuberculous lesions are frequently met with in silicotic lungs, practically unmodified. But it is very characteristic of silicosis that, when a chronic tuberculous infection affects a silicotic lung, it tends to pursue a modified and atypical course — it runs to excessive fibrosis. Small infections may go no further than to produce a scattering of large nodules of the " infective " type already described; or these may be clustered or become coalesced to form limited areas of consolidation. In more extensive infections the process takes the form of a more diffuse infective fibrosis, with the production of large masses of uniform consolidation, in which, however, the original " nodular " basis may still be discernible. In the earlier stages of their development both the isolated nodules and the larger masses are typically of a pale grey colour and of only moderately dense consistence, and indications of caseation may sometimes be apparent in them. In old-standing cases the colour is dark grey or black, and the consistence is often extremely dense, so that the larger areas may form, at this stage, more or less extensive and sometimes very extensive areas of a massive pigmented " fibroid consolidation ", such as appears in no other disease (see figs. 3, 4, 9 and 10). In some cases these areas may show no macroscopic signs of tuberculosis; in others,

---

[1] W. E. Gye and E. H. Kettle: " Silicosis and Miners' Phthisis ", *Brit. Jour. Exper. Path.*, 1922, Vol. III, p. 241; and E. H. Kettle: " Influence of Silica in determining B. Tuberculosis Infections ", *Brit. Jour. Exper. Path.*, 1924, Vol. V, p. 158.

however, areas of caseation or of a terminal necrosis with softening or cavitation may be present, and tubercle bacilli may be recovered from the necrotic material. It is to this characteristic product of the *conjunction* of a tuberculous infection with silicosis that the term "tuberculo-silicosis" was originally applied [1]. "*Tuberculo-silicosis*" *is the modification produced in silicotic lesions by a chronic tuberculous infection.* Similar changes are found in the corresponding root glands.

We have pointed out that the "infective" nodule is typically of larger size than the nodular formations of an uncomplicated silicosis, and one may say in general that in any case of silicosis an unduly large size or a marked irregularity in size in the islands of fibrosis, or a marked tendency to their coalescence is suggestive of the presence of an infective element. These variations are well brought out in the radiograph (compare, for example, films 11, 13 and 15 with films 12, 14 and 16). Indeed, in cases of advanced silicosis many of the nodules may be of the "infective" type, whether by activation of an original minute included focus of infection, or by further infection at the periphery of the nodule.

The account which has just been given of the manner in which the presence of a chronic tuberculous infection in a silicotic lung results in the production of infective lesions marked by an excessive fibrosis, suggests that other infections may in the same circumstances produce similar results. One may agree with Mavrogordato [2] and others [3] that this may occur and that areas of massive fibrosis may in some instances be the end result of the organisation of local areas of unresolved "pneumonia" of non-tuberculous origin. Again, in a good many instances of "fibroid consolidation" the appearances, both macroscopic and microscopic, suggest a simple growth and close aggregation of originally discrete silicotic nodules, in which there are no indications of tuberculous or other infection. Such a condition might result from obliteration of individual lobules and local collapse. *With the exception of the type of lesion just described, massive fibroid consolidation in the silicotic lung spells infection, past or present; and in the majority of instances the infection is tuberculous, and the lesions are "tuberculo-silicotic".*

The gross infective lesions which we have described are not often

---

[1] L. G. Irvine, *op. cit.*

[2] A. Mavrogordato: "Studies in Experimental Silicosis and other Pneumonoconioses", *op. cit.*

[3] W. Watkins-Pitchford: "The Industrial Diseases of South Africa", *op. cit.*

seen in a lung which is otherwise in a stage of quite early silicosis; they are typically a late complication. Nevertheless, in some instances, as has already been noted especially in cases which are clinically of a " phthinoid " type, well-marked circumscribed lesions of this character may be found from the first, particularly in the apical regions, although in the remainder of the lung little or no evidence of silicotic change may be present. In such cases the distribution of the lesions is that of a simple apical fibroid tuberculosis.

When a tuberculous infection develops acutely in a silicotic lung, the downward progress of the case is usually rapid. But the modification of a *chronic* infection by its conjunction with silicosis, which we have described, appears to tend to two results. The excessive fibrosis which is produced tends, on the whole, to retard the spread of the infective process to other portions of the lung and to other organs of the body, but at the same time renders it less susceptible of " cure ". The retardation and limitation of the infection which may thus be occasioned is illustrated in the film which is shown as film 18 taken from a mine official who was awarded compensation some years ago as the subject of tuberculosis with silicosis, with evidence of sub-apical infection of both lungs. The condition of this man's lungs has remained practically unchanged for five years.

Another feature of interest is frequently seen in old-standing cases of silicosis, namely the presence of extensive calcareous deposits in the nodules, indicated by the particularly bright appearance in the negative of the shadows thrown by them. In some cases the great majority of the nodules may show calcareous change. Film 17 is a good example. That this is the condition which such radiographs represent has been proved post-mortem. In view of the fact that calcareous deposit may occur in any lesion associated with excessive fatty deposit, one is not justified in accepting the hypothesis that this condition is indicative of a previous widespread tuberculous infection of the silicotic lung. It is nevertheless a striking phenomenon.

One may add here a few further observations. As we have seen, some amount of bronchitis is a constant concomitant of silicosis. Emphysema, however, is not an important feature in the early stages, although it is commonly present and may be well marked in the more advanced conditions. Cardiac dilatation and hypertrophy is uncommon in the cases we meet with nowadays, and its amount when present appears to be dependent on the degree of emphysema which exists. The presence even of extensive areas of fibroid consolidation does not in general appear to lead either to dilatation or hypertrophy of the heart. Bronchiectasis is definitely a rare complication. The results of the examination of a large series of urines in silicotic and non-silicotic miners [1] do not suggest that impairment of renal function is more common in the former than in the latter, and pathological observation supports this conclusion. Nor, so far as our local experience goes, does silicosis appear to predispose to hepatic cirrhosis.

Types and General Course of Cases of Silicosis

From what has been said it will be apparent that the actual pathological condition found in individual cases of silicosis will present many variations. The accompanying illustrations (figs. 1 to 4) may serve to give some indication of the appearances which may be met with in different types of case in miners of European stock. Figs. 4 A and 4 B represent the more grossly infective type of tuberculo-silicosis which is more characteristically met with in certain cases of the disease in native mine labourers.

There is a very significant difference of type in cases of silicosis, according as the dust factor or the infective factor is predominant in its causation or in its development. The first condition, in which the dust factor predominates because exposure to dust is heavy, produces the type of case with which we were familiar in the first twelve or fourteen years which succeeded the turn of the century; the mines then were very dusty and they were dry. It was marked by the presence of extensive fibroid consolidation, with large, bulky, heavy lungs, in which the excessive development of fibrosis overwhelmed and frequently almost wholly obscured the evidence of coincident infection, except as a rule in the terminal stage. This is the "classical" type of silicosis. But those who are familiar with the history of silicosis on the Rand are aware that, during the past fourteen years or so, coincidently with the improvement of dust conditions underground, there has occurred a progressive modification in the cases which have arisen, so that the prevalent type of infective silicosis with which we are familiar to-day is one in which the infective factor is predominant, or at least more evident, and the dust factor is relatively less prominent than formerly.

[1] *Report of Miners' Phthisis Medical Bureau for year ending 31 July 1928.* Pretoria, 1929.

Sufferers from silicosis of the "classical" type frequently retained a robust general appearance to within a few months of death. And although, of those who died from the disease, the majority died of a rapid terminal breakdown, with cavitation and emaciation, in many other cases death resulted definitely from heart failure, with cardiac dilatation, cyanosis, ascites and œdema of the lower limbs, without clinical evidence of active infection and without emaciation. One has not seen the latter mode of death for a good many years. Those who nowadays die directly from the disease do so with obvious signs of active tuberculosis, from progressive asthenia, or from hæmorrhage.

The cases which have originated within the past nine or ten years have exhibited up to a point a more progressive tendency. One reason for this may be that the diminution of dust in mine air has tended to a diminution of the limiting and retarding influence of excessive fibrosis upon the spread of infective lesions in and beyond the lung. On the other hand, in the later type of case the final stage of serious incapacitation appears to be more prolonged. The terminal break-down in the older "classical" type of case was apt to be much more rapid.

For although this change in the type of silicosis has been in part directly due to a change in occupational conditions, it has also been due in part to a change in the type of miner. The Witwatersrand miners in the early days, before and just after the South African War, were almost wholly men of overseas birth and training, derived from older long-settled and industrialised mining communities, men for the most part of originally robust physique, with a relatively high immunity to tuberculosis. But, especially in the last twenty-two years, there has been a steady increase in the number and proportion of miners of South African birth, drawn mainly from an agricultural instead of an industrialised community, and with, it may be presumed, a lower inherited or acquired immunity to tuberculosis. To-day miners of South African birth form over 70 per cent. of the "working miners", and during the past five years these men have contributed a majority of the new cases of silicosis which have arisen. One finds too to-day that men of the robust, broad-shouldered, deep-chested type (figs. 11 and 12) still run rather to the "classical" type of silicosis, and when they have acquired the disease they tolerate it much better. The originally "phthinoid" type of man, on the other hand (figs. 13 and 14), runs rather to the infective type of the disease and, having less respiratory and constitutional reserve, does not stand it so well.

We have in these remarks laid so much stress upon the importance of the infective factor in silicosis, as it occurs on the Witwatersrand, that it is perhaps desirable once more to emphasise the fact that it is uncommon to find a condition of clinically obvious tuberculosis present at the stage at which a silicosis first becomes detectable. The very great majority of cases of silicosis found amongst working miners, when first detected, are *from the clinical standpoint* cases of uncomplicated or " simple " silicosis, without evidence of obvious or " overt " tuberculosis. Nevertheless, in our belief, it remains true to say that we should not think of " simple " silicosis merely as a dust fibrosis, but as being, at least in many cases, a dust fibrosis, which from its beginning as a clinically detectable condition, is linked up with an element of latent tuberculous infection. The after-history of these cases is in this respect significant. In the majority of instances, as we said at the outset, silicosis is a progressive disease. The outlook of the individual case is mainly dependent upon whether the infective element remains " bottled up " and inactive, or whether, on the other hand, it becomes active, or a further infection occurs from outside the lung. There are wide individual differences, dependent no doubt in part upon constitutional, nutritional and environmental factors, but the tendency of the majority of cases to advance is, on the average, singularly uniform.

It may be well, in order to give concreteness to this picture, to quote a few definite figures [1]. During the three years 1920 to 1923, 728 cases of " simple silicosis ", in what is legally termed the " ante-primary " stage of the disease, were detected amongst working miners. These were cases of a " slight " or of a " moderate " degree of silicosis. At the end of the sixth year subsequent to the year of their detection, 557 of these men, or 76.5 per cent., were alive. Only some 26 per cent., however, were approximately in their original condition; 27 per cent. were in the intermediate, and some 23 per cent. were in the advanced stage of the disease. Twenty-three and a half per cent. had died, and in 18 per cent. death had been due to silicosis or to a cause (such, for example, as an acute respiratory infection) to which silicosis was regarded as having been contributory. The remainder had died from causes unconnected with silicosis.

One may put these facts in another way. Mr. Spence Fraser, Actuarial Adviser to the Union Government, informs us that the

---

[1] *Report of Miners' Phthisis Medical Bureau for year ending 31 July 1929* (in press).

average expectation of life of a case of silicosis when first detected is 13.66 years. Some, of course, will die much sooner than that; others will live longer. But *on the average* an early or " ante-primary " case will advance to the intermediate or " primary " stage in about four and a half years, and the " primary " stage case will reach the " secondary " stage of grave incapacitation in about another four years. The average time that such a miner remains in the secondary stage until he dies is seven years.

These figures indicate very clearly *the inherently progressive tendency manifest in most cases of silicosis.* That tendency depends almost wholly upon the factor of infection, and for practical purposes, apart from acute intercurrent respiratory disease, the infection which matters in these cases is tuberculosis. It is possible that the infective factor plays a more prominent role in silicosis on the Witwatersrand than it does elsewhere, since, with us, the European miners, generally speaking, work as overseers practically side by side with a very large number of native mine labourers. The African native is more susceptible to tuberculosis than the European, and, although judged by the standard of European communities the incidence of tuberculosis amongst the mine natives is not excessive, it is, by reason of their number, sufficient to constitute a definite menace. We may add that amongst the mine natives the incidence of silicosis is relatively much smaller than amongst European miners, not because the former are less susceptible to the effects of dust when subjected to similar conditions [1] but because, in general, the natives work on comparatively short individual contracts, and their total service is, on the average, not only much shorter but also less continuous. The latter fact has a very important bearing upon the hygiene of silicosis. As Dr. Mavrogordato has said, " Intermittent as opposed to continuous employment is perhaps the most effective single measure against silicosis " [2]. For these reasons, in contrast to the position amongst the European miners, the overwhelming majority of cases of compensatable disease which arise amongst mine natives are cases of active, uncomplicated tuberculosis, or, in those of longer service, of active tuberculosis preceded or accompanied by an element of silicosis [3]. It is from the side of the mine native, so far as

[1] W. Watkins-Pitchford: *Report of Miners' Phthisis Medical Bureau for year ending 31 July 1924*, p. 33.

[2] A. Mavrogordato: " The Aetiology of Silicosis ", *Rapports, Réun. Commiss. Perman. pour l'étude des Malad. Profess.*, p. 15. Lyons, 1929.

[3] *Report of Miners' Phthisis Medical Bureau for year ending 31 July 1928.* Pretoria, 1929.

underground conditions are concerned, that the danger of tuberculous infection arises, both in the production of cases of frank tuberculosis and of early infective silicosis amongst European and native employees alike.

The Immediate Causes of Death in Cases of Silicosis

We may suitably conclude this account of the clinical pathology of silicosis with the subjoined tabular statement of the actual causes of 543 deaths which have occurred amongst 1,623 cases

IMMEDIATE CAUSES OF 543 DEATHS OCCURRING IN 1,623 CASES ORIGINALLY CERTIFIED AS HAVING "SIMPLE SILICOSIS"

Immediate cause of death	Originally primary stage cases: 372 deaths (a)		Originally ante-primary stage cases: 171 deaths (b)	
Silicosis with tuberculosis	257 (69%)[1]	(76.5%)	116 (68%)[1]	(72%)
Silicosis in secondary stage without obvious tuberculosis or other specified intercurrent disease	28 (7.5%)		7 (4%)	
Influenza	7	(6.1%)	2	(5.8%)
Bronchitis	3		—	
Pneumonia	13 (3.5%)		8 (4.6%)	
Other diseases of respiratory system	1		—	
Malaria	3		1	
Dysentery	2		—	
Enteric fever	—		1	
General paralysis of insane	2		—	
Syphilis	—		1	
Aneurysm, aortitis and angina	3		2	
Valvular disease of heart	4		2	
Other diseases of heart	3		1	
Cancer of lungs (primary)	—		1	
Cancer all other sites	7		6	
Chronic rheumatism	1		—	
Alcoholism	1		—	
Cerebral haemorrhage, etc.	3		1	
Other diseases of nervous system	—		1 (acute mania)	
Nephritis	3		4	
Other genito-urinary diseases	1		—	
Diseases of prostate	—		2	
Cirrhosis of liver and hepatitis	5		1	
Appendicitis	—		1	
Intestinal obstruction	1		—	
Hernia	1		1	
Other diseases of digestive system	2		1	
Deaths by accident or injury	14	(3.7%)	10	(5.8%)
Other causes	2		1	
Undetermined	5		—	
Total	372		171	

[1] The percentages shown are percentages of the total deaths.

originally certified when first detected as being the subjects of " simple silicosis ". These cases fall into two groups:

1. The 895 cases of " simple silicosis " in the " primary " stage detected amongst working miners during the three years 1917 to 1920. Of these men, 372 had died up to 31 July 1929, and the immediate causes of death are tabulated in column (*a*).
2. The 728 cases of " simple silicosis " in the " ante-primary " stage detected amongst working miners during the three years 1920 to 1923. Of these men, 171 had died up to 31 July 1929, and the immediate causes of death are tabulated in column (*b*).

It will be seen that in both groups of these cases approximately three-quarters of the total deaths were caused directly by the disease, and that the evidence showed that recognised tuberculosis was present in 68 or 69 per cent. The close similarity in the proportion of deaths from tuberculosis with silicosis in the two groups is remarkable, since the cases in the latter group were detected when in a " slight " or " moderate " degree of silicosis only, whereas in the first group all were cases in which the disease had begun to produce some degree of disability. The inherent predisposition to tuberculosis in cases of silicosis is nevertheless seen to be practically the same in both groups, and the figures give an approximate measure of that predisposition. The only other feature of this return to which we may call attention is that acute respiratory infections, namely bronchitis and pneumonia, even when taken together with influenza, account for only some 6 per cent. of the total deaths in each group.

II. — THE RADIOLOGY AND SYMPTOMATOLOGY OF SILICOSIS

BY L. G. IRVINE, M.A., M.D., C.M., B.SC. (PUB. H.) (EDIN.), CHAIRMAN, MINERS' PHTHISIS MEDICAL BUREAU, AND W. STEUART, M.R.C.S. (ENG.), L.R.C.P. (LOND.)

General

The variations in the pathological and clinical types of the disease-complex we term silicosis, which depend partly upon the relative and actual prominence of the dust factor or of the infective factor in the cases concerned, and partly upon the type of man who is exposed to the influence of these factors, render a succinct account of the radiology and symptomatology of silicosis a matter of some difficulty.

From the medico-legal and clinical standpoint the Miners' Phthisis Medical Bureau divides the cases it deals with into the two classes of " simple silicosis " and " tuberculosis with silicosis ", according as the silicotic condition present is unaccompanied or is accompanied by *obvious, active, or " overt " tuberculosis.*

" Simple Silicosis "

All cases of silicosis which do not exhibit signs of active tuberculosis fall, therefore, under this classification, into the broad class of " simple silicosis ".

Quite a number of cases which are so classified may nevertheless present radiographic or clinical indications of a past or present infective element, which is not definitely active. Hence the Bureau distinguishes in cases of " simple silicosis " between a " predominantly silicotic " type and a " partly or predominantly infective " type of case, the latter term being applied to cases presenting clinical or radiographic indications of an old or inactive infection. The pathologist would no doubt regard cases of the latter type as instances of " infective silicosis ". But they are not cases of " tuberculosis with silicosis " in the medico-legal and clinical sense above defined.

Clinically one finds that the " robust " type of man runs, as has been seen, more to the purely silicotic or non-infective type, and evidence of infection is in such cases typically a late phenomenon. The " phthinoid " type of man, on the other hand, tends rather to the infective type from the outset. Between these extremes, however, there is a large number of intermediate cases which incline some to the one side, some to the other, in physical or in radiographic type.

If, however, one makes allowance for these variations in the disease, it is possible to divide the cases of " *simple silicosis* " which one meets with into three broad groups — the " slight " and " moderate " cases, the " well-marked " cases, and the " very well-marked " or " advanced " cases. As is to be expected in a disease which is in most instances progressive, these " stages " merge successively into one another. Nevertheless, the bulk of the cases in each group exhibit, on the average, a general correspondence in pathological condition and radiographic appearances and in the complex of signs and symptoms and degree of disability which they present.

We have seen in the preceding paper that, from the practical standpoint of effect upon respiratory function, the appearance of an appreciable or " slight " degree of silicosis may be taken to coincide in general with the development of some amount of *visible and palpable fibrosis* in the shape of a sparse " small " miliary nodulation under the pleurae and in the lung substance. This is the standard of pathological diagnosis which experience has led the Medical Bureau to adopt, and it is in this sense that the term " slight degree of silicosis " is used in the present paper.

We have seen also that, as a consequence of its mode of origin, a developed silicosis is typically a more or less *" generalised "* condition. This is an important diagnostic point, inasmuch as this feature of " generalisation " characterises alike the pathological changes, the radiographic appearances and the clinical signs of silicosis in each of its stages. Although there are exceptions in some cases of predominantly infective type, in which the lesions may be more localised and the physical signs may be correspondingly altered, the statement just made is generally applicable.

The recognition of a developed case of silicosis usually presents no difficulty. One has already called attention to the symmetrical " mottling " of the lung fields, with small and typically discrete shadows, which characterises the radiograph of an established case of what we may term a " moderate degree " of silicosis. One calls this appearance " specific ", and this kind of " mottling ", dependent upon the presence of miliary nodulation, is the *only* specific radiographic sign of silicosis.

In the film shown (film 9) this appearance is quite obvious, and it becomes more obvious still in later " stages " of the disease.

Difficulty in the matter of diagnosis can hardly arise in such established cases. The sole difficulty is naturally with cases which have not yet reached this stage of development. The question we have to answer is: " At what point can we say that the ' earliest detectable ' clinical and radiographic signs of a ' slight ' but appreciable degree of silicosis, in the sense above defined, are present ? "

We have said that a radiograph of high technical quality, properly interpreted, provides the most reliable *single* diagnostic criterion of silicosis. It may be convenient, therefore, to begin this part of our discussion by describing the indications of the presence of pulmonary " fibrosis ", as shown by the radiograph, up to the point at which these indications afford definite evidence of the existence of an appreciable degree of silicosis.

The Routine Radiological Practice at the Medical Bureau

The number of persons who have to undergo radiological examination at the Medical Bureau during the forenoon of each day averages about 120. For this reason alone the examination made is practically entirely solely a radiographic one — radioscopy is not employed as a routine method, although one fully recognises its supplementary value in detailed individual examination.

The X-ray plant used is a " Polydor ", with four-valve tube rectification of the high-tension current. Its capacity is from 35 K.V. effective to 115 K.V. effective; the output is 250 M.A.

The tubes used are line focus tubes, the " Philips' Metallix " fine focus, and the Siemens' " Phœnix Radion " medium focus, both with water-cooled anode.

The tube setting is 40 K.V. effective, with 3.8 A. heating current, giving an output of 50 M.A. Focal distance, 29 inches. Exposure, $^1/_{10}$-$^1/_5$ second for patient with average depth of chest. Films " Kodak contrast ". Intensifying screens are used at present on both sides of the film.

The Bureau's radiologist (Dr. W. Steuart) is at present investigating in Europe whether the installations using high capacity tubes, with long focal distance, recently introduced there, would prove suitable for the work of the Bureau.

Terminology Adopted by the Bureau to Describe the Various Types of Radiograph

In order to secure consistency in the description of the large number of radiographs with which it has to deal daily, the Medical Bureau has found it necessary to create a private conventional terminology, descriptive of the various general grades of radiographic appearances indicative of pulmonary " fibrosis ". The Bureau's radiologist, in reporting upon negatives, first classifies them into one of the following eight groups:

1. " Normal Thorax " (N.T.).
2. " Rather more Fibrosis than usual " (R.M.F.U.).
3. " More Fibrosis than usual " (M.F.U.).
4. " Commencing generalised Fibrosis " (C.G.F.).
5. " Moderate generalised Fibrosis " (M.G.F.).
6. " Well-marked Fibrosis " (W.M.F.).
7. " Very well-marked Fibrosis " (V.W.M.F.).
8. " Gross Fibrosis " (G.F.).

The term " fibrosis " is here used to indicate merely the amount of fibrous tissue in the lung, as indicated by the radiograph, whether that amount be within the normal limits, as in the first two or three classes, or be abnormal, as in the others. Each general group, except the first, contains two or more subdivisions; e.g. a " Well-marked Fibrosis " may be " mainly silicotic " or " partly (or mainly) infective in type ", and the particular variety present is also specified in the radiologist's report. Further, each grade may be accompanied by appearances indicative of special conditions, such as " suggestive of tuberculosis ", " apparently definite tuberculosis ", " pleural effusion ", " empyema ", " pneumonia ", " enlarged heart ", " aortic aneurism ", " pericarditis ", etc. These also are noted, if present.

The report on any individual case is made very simple by the radiologist merely initialling the relevant description upon a stereotyped form. A specimen form is attached as Appendix " A "[1] and the radiographic appearances therein reported upon are seen to be a " moderate degree of fibrosis, silicotic in type, with apparently definite tuberculosis left lung ". In this manner a hundred radiographs can easily be reported upon in much less than as many minutes.

The terms used to describe varieties of " fibrosis " are quite arbitrary and conventional, but an attempt has been made to relate them to the radiographic appearances actually shown, and to the pathological conditions indicated by these. The terminology is employed merely as a means of rapidly placing any particular negative in its appropriate approximate " bin ". Presumably all radiologists use an analogous private code, and the Bureau does not claim any particular value for the terminology which it employs, other than that of the practical convenience of securing a working uniformity of description. The precise meaning of the terms used is explained below, but for convenience of reference we append here a schematic statement which may render their general significance and relations more apparent.

The above scheme shows in tabular form the general classification of radiographic appearances adopted by the Bureau. To any one of these may be added, if the relevant indications are present, such particular additions as:

" Pleural thickening " or " pleural effusion ".
" Hilus thickening " or " peribronchial thickening ".

[1] Page 294.

TABLE I. — NOMENCLATURE OF TYPES OF RADIOGRAPH EMPLOYED BY MINERS' PHTHISIS MEDICAL BUREAU

<table>
<tr><th rowspan="2">General group</th><th colspan="3">Subdivisions</th><th rowspan="2"></th></tr>
<tr><th>(a)
Simple</th><th>(b)
Partly or mainly Silicotic in type (p. or m. Sil.)</th><th>(c)
Partly or mainly Infective in type (p. or m. Inf.)</th></tr>
<tr><td>1. N.T.
Normal Thorax</td><td>Normal shadows</td><td>—</td><td>—</td><td rowspan="8">If the radiograph shows indications of active Tuberculous infection, substitute for Group 1, or add to any of the other groups, “ Suggestive of Tuberculosis ”, or “ Apparently definite Tuberculosis ”</td></tr>
<tr><td>2. R.M.F.U.
Rather more Fibrosis than usual</td><td>Simple
(slight increase of fibrosis in normal situations)</td><td>—</td><td>p. or m. Inf.
(as in (a), with indications of old or inactive infective element)</td></tr>
<tr><td>3. M.F.U.
More Fibrosis than usual</td><td>(Further increase of fibrosis in normal situations ; “ large branch fibrosis”)</td><td>—</td><td>,,</td></tr>
<tr><td>4. C.G.F.
Commencing generalised Fibrosis</td><td>Simple
(generalised fine arborisation throughout both lung fields; “ small branch fibrosis ”; “ the leafless tree ”)</td><td>partly Silicotic in type
(as in (a), with partial “ small ” specific mottling)</td><td>p. or m. Inf.
(as in (a), with indications of infective element not definitely active)</td></tr>
<tr><td>5. M.G.F.
Moderate generalised Fibrosis</td><td>Simple
(as above, but more marked)</td><td>Silicotic in type
(symmetrical “small” mottling throughout both lung fields)</td><td>p. Inf.
(as in (a) or (b), with indications of infective element not definitely active)</td></tr>
<tr><td>6. W.M.F.
Well-marked Fibrosis</td><td>—</td><td>(Symmetrical “ medium ” mottling)</td><td>(as in (b), with indications of infective element not definitely active)</td></tr>
<tr><td>7. V.W.M.F.
Very well-marked Fibrosis</td><td>—</td><td>(Symmetrical “ large ” mottling)</td><td>,,</td></tr>
<tr><td>8. G.F.
Gross Fibrosis</td><td>—</td><td>(Gross mottling)</td><td>,,</td></tr>
</table>

" Consolidation " not regarded as tuberculous, e.g. from pneumonia.
" Heart enlarged " or " heart asthenic in type ".
" Aorta enlarged " or " aortic aneurysm ".
" Other changes, e.g. " ? neoplasm ", " ? hydatid ", etc.

The term " fibrosis " is here used merely to indicate the amount of fibrous tissue in the lungs, as shown by the radiograph. The increase in " fibrosis " indicated in Groups 2(*a*) and 3(*a*) is within limits which are not in general of pathological significance. The increase indicated in Group 4(*a*) is of pathological significance, but is not *necessarily* of silicotic origin ; the same is true of Group 4(*c*). Group 4(*b*) is specifically indicative of a " slight " degree of clinically simple silicosis; Group 5(*b*) of a " moderate " degree. Groups 6(*b*), 7(*b*) and 8(*b*) indicate, respectively, a " well-marked " and finally a " gross " degree of clinically simple silicosis.

Radiographic Appearances in Minor Degrees of " Fibrosis "

This being premised, one may proceed to indicate the precise meaning of the terms used and their application to diagnosis. The type described as " Normal Thorax " (N.T., film 1) ought perhaps to be described as the " ideal " normal thorax. It is present in only a minority of adult males of working age.

The type described as " Rather More Fibrosis than Usual " (R.M.F.U., film 2) shows, as compared with the former type, a slight increase of fibrosis in normal situations. The difference is not in general of pathological significance; indeed this type of plate is probably the most common amongst healthy adult males of working age. It shows the heart shadow of the normal shape; the hilus shadows are of normal density and extent; and radiating from these are the branching shadows thrown by the larger bronchi and blood vessels, which extend some distance into the lung fields. *Between and beyond these shadows the lung fields are clear.* Even in " normal " radiographs taken from perfectly healthy persons there may be found a few sharply defined bright spots in the lung fields and a similar appearance in one or two of the root glands, indicative of an old healed " primary " tuberculous infection in early life, which has left no other trace.

The next type of film is that termed by the Bureau's radiologist " More Fibrosis that Usual " (M.F.U., film 4). It shows an advance on the previous type in the form of an increase in the number and extent of the branching shadows spreading from the hilar areas. These are now more numerous, and may generally be traced almost to the periphery of the lung. They remain, however, dendritic or linear in form. The hilus shadows are rather more obvious; the heart shadow remains normal in shape. The condition represents a further increase in fibrous tissue in normal situations. It may be described as a " large branch fibrosis ", the shadows shown in the lung fields being for the most part thrown by the larger branches of the bronchial or vascular trees. This type of film is not necessarily, or even as a rule, of pathological significance. It is seen in about 25 per cent. of all initial examinees, and in well over 50 per cent. of those of forty-five years or over, since there is, as life advances, a normal increase in the fibrous tissue of the lung framework. This type of radiograph is frequently seen in cases of chronic bronchitis and bronchial asthma and chronic valvular disease of the heart, and is common, together with other signs, in cases of " old healed tuberculosis ". As is to be expected, it is more common in miners, age for age, than in those who have not been underground; but pathological evidence shows that it is not in itself indicative of silicosis.

Minor Degrees of " Fibrosis " of Infective Type

Running parallel to the two simple types of radiograph just described, there are two other types (films 3 and 5) which, although similar in most respects, nevertheless show certain definite differences. They show respectively practically the same amount of fibrosis as in the " rather more fibrosis than usual ", or " more fibrosis than usual " types which we have discussed. But in each case the evidence of fibrosis is now accompanied by features which distinguish these films rather sharply from the former ones, inasmuch as *in each the fibrosis is associated with signs indicative or suggestive of a limited amount of former tuberculous infection* of hilar or peribronchial type. It is associated with a change in the shape of the heart to the narrowed, elongated, " asthenic " or " vertical " form, and with a definite or marked increase in the hilus and bronchial shadows, indicative of glandular enlargement and peribronchial fibrosis of infective origin. Denser shadows cast by markedly fibrosed or calcareous lesions may be apparent at or near the hilus region, or here and there in the lung fields. Clinically, individuals who show this type of radiograph may be quite healthy and fit for ordinary work, but they are not in general of robust physique. They are almost always under weight, sometimes markedly so, with a flat or flattish chest, a defective posture, sometimes with " winged " scapulae, and they usually are somewhat languid-eyed or " deep-eyed ". They have, in short, as a rule the characteristic physical stigmata of the " phthinoid " type of individual, associated with radiographic indications of an old " healed " pulmonary infection. The Medical Bureau therefore labels this type of radiograph " Rather More Fibrosis than Usual, partly Infective in type " (R.M.F.U. p. Inf., film 3), or " More Fibrosis than Usual, partly Infective in type " (M.F.U., p. Inf., film 4).

Those who are familiar with the radiographs shown by cases of simple tuberculosis will at once recognise these varieties.

It is remarkable how close the correlation between the radiograph and the clinical condition generally is in this group of cases. Cases of this class are never passed for underground work by the Bureau. But there is no difficulty in obtaining representative films of each of these varieties in persons who have never worked underground; indeed, some 4 per cent. of the average " healthy " males of working age, who present themselves as possible recruits for mining, have radiographs actually or approximately of one or other of the types shown in films 3 and 5. *Films of this character are not in general indicative of silicosis;* they are generally speaking indicative of an old tuberculous infection.

" Commencing Generalised Fibrosis "

Silicosis, as we have said, is a *generalised* condition, and the earliest type of radiograph which gives indication of a commencing generalised increase of fibrous tissue in the lung is that indicated by the next group of films, which are termed " Commencing Generalised Fibrosis " (C.G.F., films 6, 7 and 8). In the Bureau's terminology there are three varieties of this group: 1. " Simple Commencing Generalised Fibrosis " (film 6); 2. " Commencing Generalised Fibrosis, partly Silicotic in type " (film 7); and 3. " Commencing Generalised Fibrosis, partly Infective in type " (film 8). The terms may seem cumbrous, but they represent definite distinctions.

The feature common to them all is the appearance of a well-marked generalised fine " arborisation " in the lung fields. The radiograph shows an advance on the previous type (M.F.U., film 4) in the appearance of additional finer dendritic or reticular shadows cast by the smaller air tubes or blood vessels and apparent more or less generally throughout the lung fields.

In the variety termed "Simple Commencing Generalised Fibrosis" (S.C.G.F., film 6) the description just given is all that is apparent. The heart shadow is normal; the hilar shadows are increased; the lung fields show the generalised arborisation which we have described. The appearances suggest the branching of a leafless tree *in which the smallest branches have now become apparent.* There is no evidence, however, of any definite amount of specific silicotic "mottling". The appearance described cannot be regarded as being unequivocally "specific" of silicosis. Similar indications may be given by other conditions, by peribronchial tuberculosis (to which we shall refer in a moment), by chronic bronchitis not associated with special exposure to dust, possibly by pulmonary syphilis, and may be found in some cases of chronic cardiac or cardio-vascular disease. It is sometimes seen in coal miners who arrive from overseas to apply for work in the gold mines, and does not appear in them to lead to anything more serious or to be accompanied by any incapacity. It begins to be evident in a small percentage of our miners who have worked about ten years or so underground, and is found in them to correspond in general to the condition of fine thickening of the branches of the bronchial and vascular trees, unassociated with palpable fibrosis, which was described in the previous paper, as preceding the development of a definite condition of silicosis. It was there suggested that this characteristic appearance was probably in large measure dependent upon changes in the bronchial tree induced by bronchitis and bronchiolitis. Pathological investigation shows that, in a majority of instances, the lungs of individuals who have shown this appearance in radiographs taken during life do now exhibit definite evidence of silicosis post-mortem. *This particular type of film therefore cannot be taken as affording a general standard diagnostic of the presence of silicosis.* On the other hand, in a *minority* of cases, a "slight" degree of silicosis has been found post-mortem in individuals whose chests during life had shown a simple fibrosis of this type.

The Earliest "Specific" Radiographic Indications of Silicosis

The second variety of the group of radiographs we are discussing is termed "Commencing Generalised Fibrosis, partly Silicotic in type" (C.G.F., p. Sil., film 7). The general background of "arborisation" is the same as in the radiograph last described.

But in some areas here and there, commonly first towards the upper poles of one or both lungs, *local evidence of specific " mottling " is beginning to appear.* The leafless tree is beginning to put on leaves. Pathological evidence shows that in practically all instances this appearance in the radiograph represents the sparse beginnings of palpable miliary nodulation, which marks the development of a " slight " degree of silicosis. The clinical signs will be found also to correspond, and the conjunction clinches the diagnosis.

In all cases in which the appearance described is found to develop in a miner, or is present in a claimant whose industrial history includes a period of several years' work underground, a diagnosis of silicosis may safely be made. *The Medical Bureau, accordingly, accepts a radiograph of this type as the general radiographic standard of diagnosis of the " earliest detectable " stage of simple silicosis. It is the earliest type of film which gives unequivocal specific evidence of the disease.*

In practice, however, the Bureau is accustomed to allow a certain degree of latitude in the application of this general standard, inasmuch as pathological evidence shows, as we have said, that a slight degree of silicosis may sometimes be found after death in individuals whose chests during life had shown the appearance merely of a simple " commencing generalised fibrosis ". If these appearances develop under observation in a miner during the course of underground work and are accompanied by a coincident development of *definite* clinical evidence of pulmonary fibrosis, and of some respiratory disability not attributable to other causes, a diagnosis of a " slight " degree of silicosis may be made. The possible presence of bronchitis and bronchiolitis is of importance in this respect. But in such cases the confirmatory clinical evidence must be unmistakable, and the occupational history convincing.

The same qualification applies to the evidence afforded by the third type of film of this group, named " Commencing Generalised Fibrosis, partly Infective in type " (film 8, with which we may associate film 10). These films are similar in general character to those already referred to (films 3 and 5) as illustrating minor degrees of " fibrosis " of infective type, but they show a more extensive condition of " fibrosis ". Like these they are indicative in general of an old tuberculous infection. They resemble the type of film shown in cases of a limited degree of simple apical fibroid tuberculosis. Indeed, beyond one or two enlarged and fibrosed root glands and a possible old pleural scar and a few cretaceous or fibroid nodules at the apices or elsewhere, there is usually very little macroscopic change detectable post-mortem in lungs which have shown appearances of this sort during life. Radiographs of this type may be met with amongst individuals who have never been underground at all. But they are certainly commoner amongst miners who have spent a good many years underground than amongst non-miners. Such appearances may be accompanied by no deterioration of general health or respiratory function in the individuals concerned. Nevertheless, a certain proportion of cases of the type, represented by films 8 and 10, occurring in miners, have been found, post-mortem, to show evidence of a slight degree of slowly progressive tuberculo-silicosis. This takes the form usually of one or two circumscribed areas of tuberculo-silicotic consolidation at or towards one or both apices, with a scattering of smaller nodules in the neighbourhood, with thickening and perhaps adhesion of the overlying pleura, and with similar tuberculo-silicotic changes in the corresponding root glands. If these lesions are enough to " matter " they will, with practical certainty, be indicated in a good radiograph. But there is no generalised silicosis. One is here dealing with *a slight localised degree of tuberculo-silicosis.* Persons showing this condition are usually spare and not robust, and incline to the " phthinoid " type of chest.

It is accordingly the practice of the Medical Bureau that, when a radiograph of this infective type of " Commencing Generalised Fibrosis " (film No. 9), with indications of localised apical change, is found to have developed during the course of his employment in a miner who, although showing no signs of active infection, presents evidence of some progressive deterioration in general condition and respiratory function, together with physical signs of pulmonary fibrosis, to certify the presence of a *slight degree of tuberculo-silicosis.* Such a condition is the characteristic expression of a limited tuberculous infection in a person exposed to the inhalation of dust in moderate amounts.

One hopes that what has so far been said regarding the diagnosis of the " earliest detectable stages " of silicosis has not left a sense of indefiniteness. The position amounts to this. The *general* diagnostic standard is the film, which shows the first indications of specific " mottling " (film No. 7), and a considerable majority of the cases notified fall into this group. But pathological evidence indicates that we are justified in extending our basis of selection to include a certain number of cases whose radiographs are of the " simple " or " infective " varieties of " simple generalised fibrosis ", *provided that we have ample support from the clinical side and from the industrial history in so doing.* That is the position which corresponds to the facts of the case. But this situation suggests all the more the desirability of placing all decisions which may lead to awards under a system of compensation in the hands of a specially selected body of whole-time examiners, whose expert experience of all aspects of the question will enable them to give an impartial decision.

The Clinical Signs in a " Slight " or " Moderate " Degree of " Simple Silicosis " [1]

One may now consider the nature of the clinical signs which are usually present at the " earliest detectable " stage of silicosis.

It will readily be understood that, in a condition whose pathological beginnings are fine and generalised, and whose development is extremely gradual, the symptoms will be correspondingly insidious in their onset and more elusive in character than is the case with most other lung diseases. This is certainly so, and constitutes the unquestionable and unavoidable difficulty in diagnosing the disease by ordinary clinical methods in its earliest stage.

The usual *symptoms* of silicosis in its " earliest detectable stage " are *slight shortness of breath on exertion*, with some amount of *irritative cough*, typically a dry cough with little or no expectoration, often worst in the morning and sometimes inducing vomiting. There may also be some complaint of occasional slight pains in the chest. Even these symptoms may be absent, and, in not a few cases, miners, when notified that they have contracted a " slight " degree of silicosis, may be unaware that there is anything the matter with them. Further, these symptoms in themselves are not peculiar to silicosis, and in no case is the Medical Bureau influenced in its decision *solely* by such subjective evidence. In general one may state that at this stage respiratory disability is, at the most, slight, and it may be altogether absent.

To come now to *physical signs*. In the earliest stage of a " simple silicosis " there is no departure from the normal standard of nutrition, except in individuals of an originally poor physique. Loss

[1] The succeeding portions of the present paper are based, with however a considerable amount of expansion and modification, upon an account of " The Diagnosis of Silicosis and Tuberculosis in the practice of the Medical Bureau ", prepared by one of us (L. G. Irvine) in conjunction with Dr. J. M. Smith, and published in *The Proceedings of the Transvaal Mine Medical Officers' Association*, Vol. I, No. 6, Sept. 1921.

of weight, which occurs coincidently with the development of signs of silicosis, and which cannot be attributed to other causes, definitely suggests an infective element in the case.

The conformation of the chest usually shows little or no alteration, although the upper chest may show some flattening. The percussion note is typically of *average* normal quality. The practically constant clinical signs are:

1. A certain lack of elasticity of the chest wall during the movements of respiration, together with
2. A somewhat reduced air entry, and
3. A characteristic alteration of the inspiratory murmur from the normal " vesicular " character to a higher-pitched or " harshened ", " thinned " and commonly somewhat shortened type, the expiratory murmur, although somewhat prolonged, remaining fainter than the inspiratory.

This type of breath-sound is very characteristic, with some modifications, of silicosis in all its stages, and this clinical sign has also the significant character of more or less complete *generalisation*. It is first noticeable at the anterior, lateral and basal regions.

In a minority of cases, however, the breath-sounds may be simply diminished, but breath-sounds which are simply diminished or which, on the other hand, are merely somewhat louder or more " pronounced " than normal, are not specially characteristic of silicosis.

Usually there are no accompaniments, but a stray rhonchus may be heard here and there.

This complex of physical signs is almost constantly present in cases of a slight degree of " simple " silicosis. The cough may be put down to the coincident bronchitis and bronchiolitis, the recurrent pains to slight intercurrent local pleurisies.

The clinical condition is not much more marked in each of its components in cases of a " moderate " degree. The radiographic appearance of the latter condition is, however, now quite distinctive. It is that described by the Bureau as a " Moderate Generalised Fibrosis, Silicotic in type " (M.G.F. Sil., film No. 9), to which we have already referred. The partial indications of the specific " mottling " shown in film No. 7 are replaced by a symmetrical and practically uniform distribution of this appearance over the whole of both lung fields. The latter are seen to be occupied practically throughout by numerous small discrete shadows cast by individual nodules or (in part) by slightly thickened air tubes or blood vessels caught " end on ". We are here obviously dealing with an established condition of silicosis, and its radiographic appearance is now unmistakable. It is simulated by no other condition, except by some cases of acute miliary pulmonary tuberculosis. In the latter, however, although the distribution of the small discrete shadows is practically identical, the individual shadows are less well defined, and clinically the differential diagnosis should present no difficulty.

Individuals who show the "infective" type of "slight" or "moderate" silicosis are most often of "phthinoid" conformation and aspect, and, apart from these characters, the physical and radiographic signs may be more marked at the apical regions of the lungs.

Clinical and Radiographic Signs in a "Well-Marked" Degree of "Simple Silicosis"

The description of the later stages of silicosis need not occupy us long. In cases which have passed from the earlier stage of a "moderate" to that of a definitely established "well-marked" degree of simple silicosis the radiographic and clinical signs are very distinctive.

The *radiographic appearances* are those shown in the type of film termed "*Well-marked Fibrosis of Silicotic type*" (W.M.F. Sil., film No. 11). This exhibits the characteristic "mottling" in a more marked degree. The individual shadows are larger, although they may not be more numerous. They are of a fairly well defined, rounded or sometimes annular form, generally discrete, but sometimes, in places, merging somewhat into one another. The heart remains of good shape. This is the characteristic picture.

If, on the other hand, the "mottled" shadows are irregular in shape, size and distribution, and are accompanied by a change in the heart shadow towards the vertical type, the presence of an infective element, which is commonly tuberculous, may usually be assumed, although there may be no clinical indications of active pulmonary infection. Compare in this respect film 11 with film 12.

In a fair proportion of cases another and very striking change may be manifest, namely, that many or most of the individual shadows may be seen (in the negative) to be abnormally bright and sharp, owing to an increased density of the individual nodules (film 17). Pathological evidence has confirmed the view which had previously been taken by the Bureau that this remarkable and suggestive feature is due to calcareous deposit occurring in the nodules, and this change may extend to the great majority. No microtome will touch them.

Finally, one may add that a coarsely " mottled " appearance may be seen also in some cases of simple broncho-pneumonic tuberculosis. But in these the appearance is rarely generalised throughout both lungs, the shadows of " mottling " are less sharply defined and may commonly be seen to merge into a more diffuse opacity at the apex or round the hilus.

The *clinical signs* in the intermediate or " well-marked " stage of simple silicosis show a corresponding advance upon those of the earlier stages. They now present a characteristic complex.

In a case of average or of robust type the man is usually quite well nourished, and indeed is not at all infrequently well above the normal weight. The upper chest is typically somewhat — but " smoothly " — flattened or " sloping " but is not markedly retracted, as in chronic tuberculosis (cf. fig. 12). The character of the chest movement is modified, as much, however, by an alteration in the *quality* of the movement, which is sluggish and lacking in elasticity, as by a mere reduction of the *range* of movement, although some amount of reduction is the rule.

The percussion note, without being definitely " dull ", is usually somewhat flattened, particularly posteriorly.

The air entry is somewhat shortened and thinned. The breath sounds are also typically somewhat shortened and present almost constantly and more definitely the characteristic thinning and harshening of inspiration, together with a prolonged but fainter expiration, already described, although in a small minority of cases, at this stage also, the breath sounds are simply " diminished vesicular " in character.

The silicotic chest, in the absence of complication due to infection, is typically a " dry " chest, although sometimes fine crepitations, due to congestion, may be heard towards the lateral and basal margins, or a few rhonchi may be heard here and there. Cough too, if complained of, is usually " dry " and irritative, often of the morning " emetic " type.

In the cases which we see nowadays cardiac dilatation, except when dependent on intrinsic disease of the heart, is quite exceptional at this stage of silicosis.

Cases of silicosis in the intermediate stage are usually fit for " moderate " physical work; indeed, a number of cases who show the radiographic signs of a well-marked silicosis may lead a full, active life, without obvious interference with respiratory function. But in an average case there is an amount of dyspnoea on exertion which definitely impairs the working capacity.

Simple silicosis of the " classical " type is not typically a wasting disease. As we have said, even in well-marked cases the general condition and appearance may be quite good, and there is actually in a number of cases a tendency to gain weight coincidently with the onset of detectable evidence of the disease. In others, however, there is loss of weight, and this is more common in those whose radiographs are of the " infective " type which I have described, circumstances that suggest the presence in such cases of an element of latent infection.

The Advanced Stage of " Simple Silicosis "

Twenty years ago it was common enough to meet with advanced cases of " simple " silicosis which were not obviously of an infective type. To-day one meets with cases which can fairly be described as such, generally speaking only in men of originally robust physique. A characteristic example is shown in fig. 11, already referred to.

The *radiographic signs* in such cases are those of a medium or large, close mottling, and the shadows may be seen here and there to have coalesced, giving the appearance of limited areas of more diffuse opacity (films 13 and 15). If the shadows show much lack of definition and are unduly large or irregular in size, with a definite tendency to local coalescence, it is probable that an infective element is present in the case (films 14 and 16). Indeed, the first radiographic indication of the supervention of an active tuberculosis is frequently the occurrence of a blurring of the outline of the " mottled " shadows which, in previous radiographs taken in the same case, may have been well defined.

Few cases of advanced silicosis are without some infective element, although this may be latent and not apparent clinically.

In advanced cases of the " classical " type (films 13 and 15) the *clinical signs* are very pronounced. The general nutrition may be quite good; many cases indeed are somewhat obese. There are, with few exceptions, some cyanosis and some obvious dyspnoea; in some the expression may be rather " anxious ". The chest is smoothly flattened, without however showing marked retraction. The intercostal and supraclavicular spaces may show no obvious hollowing. The configuration resembles that of a moderate emphysema, and a greater or less amount of emphysema is a constant feature of the condition (cf. fig. 11). Expansion is decidedly impaired, both qualitatively and quantitatively, and the range of movement is decidedly limited. The percussion note is flat, without being absolutely dull, although there may be local areas of dullness due to thickened pleura. To the percussing finger the normal resilience of the chest wall is impaired. The vocal resonance may be generally increased, but frequently it lacks " ring ", and so too may the voice. The air entry is decidedly reduced and short. The respiratory murmur is *short* and high-pitched, sometimes thin, sometimes rather blowing, although it may (but much less usually) be merely much reduced and faint. The condition of the pleuræ may to a large extent account for these differences. There may be signs of localised consolidation, but these, if extensive, point to an infective complication.

As we have said, it was formerly not uncommon for cases of advanced silicosis to die from a progressive heart failure, with cardiac dilatation, cyanosis and dropsy. But death by progressive heart failure occurs very rarely nowadays, since few cases now exhibit the excessive degree of fibrosis which determined that mode of death. A definite cardiac dilatation secondary to silicosis is relatively uncommon in the cases we meet with at present, although some amount of fine crepitation, due to congestion, is very frequently present towards the lateral and basal margins of the lungs. Nor is there any evidence in our cases of a higher proportion of instances of disordered renal function amongst silicotic than amongst non-silicotic miners.

To-day cases such as we have just described are uncommon. The greater number of advanced cases of " miners' phthisis " are nowadays cases of " tuberculosis with silicosis "; and the majority of the remainder, who have so far escaped an active breakdown, and for that reason are still classed as " simple silicosis ", nevertheless show clinical and radiographic indications of the presence of a latent infective element. (Cf. films 14 and 16.)

Cases of advanced silicosis are in general fit for light work only, or for no physical work whatever, although even at this stage some may be able to lead a moderately active life.

Functional Tests in Cases of " Simple Silicosis "

A preliminary series of functional tests was carried out at the Bureau both upon miners and non-miners by Mr. J. H. Dowds, of the Witwatersrand University, in 1924; and a further and more extended series of similar observations was conducted by him at the beginning of the present year, in order to obtain an approximate measure of several of the clinical features found in silicosis, and in order to determine the possible value of such tests in diagnosis.

Observations were made upon 500 cases, which were divided into five groups, each represented by 100 individuals. The groups chosen for observation were:

1. " First Periodicals " i.e. men who had been underground for not more than six months and all of whom had passed the " initial " examination of the Bureau as new recruits.
2. " Short-service Miners ", i.e. men working in their fifth, sixth or seventh years of underground service; all of these men also had passed the initial examination of the Bureau.

These two groups are therefore comparable with each other, since all had undergone special selection in respect of their physique prior to entering on underground work. The observations made in these 200 cases may be of particular value in the future when the further history of these men is followed.

3. " Long-service Miners ", i.e. men working in their eleventh, twelfth and thirteenth years of underground service. Very few of these men had passed the initial examination of the Bureau, and they were in general a group the members of which had not undergone any special selection. They are therefore not, as a class, comparable with the first two groups, but they are comparable with the two succeeding groups, which are also in general composed of men who had not passed the initial examination of the Bureau.
4. Cases of " Ante-primary " stage silicosis, examined either at the time of their certification or at their first re-examination thereafter.
5. Cases of " Primary " stage silicosis.

With only one or two exceptions, all of these men had worked underground solely on the Witwatersrand. Men under twenty or over fifty years of age were not examined, the latter precaution was taken in order to exclude persons suffering from simple senile changes. Very obese men were excluded, also cases of chronic heart disease, subjects of present or recent illness or recent operation, and persons suffering from hookworm infection, or those in whom there was evidence of tuberculosis, or men who obviously were not trying to execute any of the tests properly. With these exceptions, the men were taken as they came.

The sequence of the tests used was: resting respiratory rate, resting pulse rate, stool-stepping test, chest expansion, vital capacity, total lung ventilation per minute, blood pressure (silicotics only) and haemoglobin percentage.

TABLE II. — AVERAGE RESULTS OF PHYSICAL MEASUREMENTS IN CERTAIN GROUPS OF NON-SILICOTIC AND SILICOTIC MINERS

	Group I: 100 first periodicals	Group II: 100 short-service miners	Group III: 100 long-service miners	Group IV: 100 ante-primary stage silicotics	Group V: 100 primary stage silicotics	Group VI: 10 secondary stage silicotics
Age (years)	25	34	38	40	42	44
Height (cm.)	170	170	169	171	169	170
Weight (kg.)	70	70.5	66.5	70	66.5	67
Mean standard weight (kg.)	66.5	68.0	68.5	71	69.5	70.5
Service underground (years)	0. 4m.	6. 7m.	12. 4m.	12	9. 11m.	10
Respiratory rate (per minute):						
At rest, standing	18	19	20	23	23	24
Increase immediately after exercise	3	4	5	6	7	7
Increase remaining after pulse returned to normal	1	2	5	5	5	4
Pulse rate (per minute):						
At rest, standing	77	77	81	87	86	86
Maximum increase after exercise	31	28	28	27	27	27
Time (seconds) for return to normal	34	42	45	53	53	67
Chest circumference at end of normal expiration:						
2 ins. above nipple (cm.)	92	92	91	93.5	90	91
2 ins. below nipple (cm.)	85	85	85	86.7	85	87
Average range of expansion between full inspiration and full expiration (cm.)	9	8	7	6.5	5.5	4
Actual vital capacity (cc.)	4710	4440	4090	4020	3610	3190
Percentage deviation of vital capacity from calculated standard value	+10.7	+4.4	—3.2	—6.3	—14.6	—24.9
Ventilation per minute (cc.)	10790	10680	11340	11440	11720	12690
Ditto, per kg. body weight	154	151	170	163	176	189
Alteration respiratory rate on breathing through spirometer	—0.5	—0.4	+0.7	—0.4	+1	+1.5
Tidal air (cc.)	663	603	589	583	539	506
Ventilation per min. ÷ Vital capacity	2.31	2.43	2.81	2.91	3.31	4.41
Resp. rate (spirometer) × Ventilation per minute ÷ Vital capacity	41.3	46.6	59.8	64.1	80.5	121.2
Percentage haemoglobin	89	89	89	89	89	89
Blood pressure:						
Systolic	—	—	—	131	130	131
Diastolic	—	—	—	93	91	91
Pulse pressure	—	—	—	38	39	40

Flack's test (respiratory force) was not employed, as its results in the preliminary series of observations were erratic. An effort-test of stool-stepping (10 times in 30 seconds; height of stool, 20 inches) was employed instead, and the alterations of pulse and respiration were observed.

The average results are shown in table II.

In the last vertical column a series of observations on ten secondary stage cases has been added; the number is small, but the results so far as they go are consistent.

These observations show a progressive diminution in chest expansion in silicotic cases. The vital capacity is also progressively reduced, but only slightly so in ante-primary stage cases; in primary stage cases the average reduction is of the order of 15 per cent.; the resting respiratory rate is increased and the breathing becomes proportionately shallower.

These results are of interest, but the great variations shown by individual cases in each group and the element of uncertainty which might readily be introduced by the subjective factor in such tests render them of little value in diagnosis. The observations on the average blood pressure in cases of silicosis are of interest from their negative result.

"Tuberculosis with Silicosis"

By the term "Tuberculosis with Silicosis" one means silicosis complicated by clinically obvious, active or "overt" tuberculosis. Mere indications from the radiograph or from physical signs of limited areas of consolidation do not lead one to place a case in this class unless there are local or constitutional signs of *active* tuberculous infection. Active tuberculosis may be present from the first appearance of detectable signs of silicosis, but this is uncommon. It may supervene at any stage in the progress of what has previously been from the clinical standpoint a condition of simple silicosis. But it is most common as a terminal complication in well-marked or in advanced cases of the disease.

The diagnostic indications of silicosis complicated by tuberculosis are that the signs, particularly the radiographic signs, of *both* conditions are present.

In the radiograph, in addition to the generalised signs of silicosis in one or other of its stages, indications of more or less extensive "blurring" or of more marked local opacities indicative of areas of definite consolidation appear (see films 19, 20, 21 and 22). The heart shadow also may show a change to the asthenic or "vertical" type.

The radiograph is particularly helpful in such mixed conditions, especially when these are seen for the first time, and it is usually decisive. It is a common and easy course, when a case of active tuberculosis is met with in a miner, to *assume* the presence of a silicotic element. But such a diagnosis, when made on clinical grounds alone, is in very many cases merely presumptive. The only objective *proof* of such a conjunction during life is the radiograph, which will almost invariably give precise and accurate indications of the actual condition present. In some instances, however, the appearances produced in the radiograph by an extensive bilateral tuberculosis may altogether obscure the distinctive indications of an underlying silicosis. In such cases one is compelled to fall back on the probabilities of the case, taking into consideration the previous condition of the individual and the duration and character of his underground service. The same observation applies to some old-standing cases of chronic "tuberculo-silicosis", in which the distribution of the lesions resembles that of a fibroid tuberculosis, and in which no indications of a generalised silicosis may be present.

On the *clinical* side the supervention of *active* tuberculosis is shown first usually by a definite and progressive loss of weight, by the appearance of evidence of localised areas of infection in the lungs or pleurae, with their characteristic physical signs, by increased cough and expectoration, sometimes with hæmoptysis, and commonly by a rapid break-down in the patient's condition. Examination of the sputum for the tubercle bacillus should, of course, always be made; its presence is a more ominous sign in tuberculosis complicated by silicosis than in cases of simple tuberculosis. It is a characteristic feature that, when an overt tuberculosis becomes manifest in a case of well-marked silicosis, the amount of dyspnoea appears to be quite out of proportion to the actual extent of the infection. This is one side of the picture. The other side is that, as we have already said, not a few cases of "tuberculo-silicosis", in which the infective element is less acute, may run a very chronic course, with a well-marked tendency to retardation and limitation of the infection (cf. film 18).

In conclusion, an interesting observation may be mentioned, namely that the onset of a tuberculous infection in a lung in which no radiographic or clinical signs of silicosis were previously detectable may sometimes bring to light a condition of what Watkins-Pitchford has termed " latent silicosis " [1]. The infection appears to select the sites in the lung where minute aggregations of silica are already present, and thus to assume the characteristic " miliary " distribution of a silicosis. This feature, when it occurs, commonly does so within a comparatively short time of the appearance of evidence of infection.

Legal Definitions of the " Stages " of Silicosis

We should have liked to add a few remarks regarding the differential diagnosis of silicosis, but what has been said is possibly sufficient to indicate the general features which distinguish that disease from other pulmonary conditions, and one does not wish to extend this discussion unduly.

It may, however, be of interest from a practical point of view to quote in conclusion the definitions of the three legal " stages " into which, for purposes of compensation, cases of silicosis are classified under the Miners' Phthisis Act of 1925, of the Union of South Africa. This will enable one to form an idea as to how the varying types of case which we meet with may be fitted into a legal system of compensation.

The definitions of silicosis in the Act mentioned (section 76 (2)) are as follows:

2. For the purposes of this Act . . . the expression " silicosis " shall mean silicosis of the lungs. A person shall, for the purposes of this Act, be deemed to have or to have had silicosis

(a) in the *ante-primary stage*, when it is found by the Bureau that the earliest detectable specific physical signs of silicosis are or have been present; whether or not capacity for work is or has been impaired by such silicosis;

(b) in the *primary stage*, when it is found by the Bureau that definite and specific physical signs of silicosis are or have been present, and that capacity for work is or has been impaired by that disease, though not seriously and permanently;

(c) in the *secondary stage*, when it is found by the Bureau that definite and specific physical signs of silicosis are or have been present, and that capacity for work is or has been seriously and permanently impaired by that disease, or when it is found by the Bureau that tuberculosis with silicosis is or has been present.

---

[1] W. Watkins-Pitchford: " The Silicosis of the South African Gold Mines. " *Journ. Indust. Hygiene*, Vol. IX, No. 4, p. 113.

The definition of tuberculosis (section 76 (3)) reads as follows:

3. For the purposes of this Act . . . " tuberculosis " shall mean tuberculosis of the lungs or of the respiratory organs. A person shall, for the purposes of this Act, be deemed to be suffering from tuberculosis whenever it is found by the Bureau either

(*a*) that such person is expectorating the tubercle bacillus; or

(*b*) that such person has closed tuberculosis to such a degree as seriously to impair his working capacity and render prohibition of his working underground advisable in the interests of his health.

It may be noted that the terms " is ", " are ", " has " or " have " in the above definitions apply to the cases of living miners; " has been "; " have been " or " have had " to those of deceased miners.

We may add one or two explanatory observations upon these definitions:

1. It will be noted that cases of *tuberculosis* do not come within the provisions of the Miners' Phthisis Act unless they are either " open " cases or cases which are productive of *serious* impairment of working capacity. Minor degrees of " old " healed tubercle or " latent " tubercle which do not cause serious incapacity are not cases of " tuberculosis " as defined.

It is recognised that it is very undesirable for any person who is the subject of active simple tuberculosis to continue to work underground, alike in his own interest and that of his fellow workmen. All working miners who are found to have simple tuberculosis are therefore debarred from further work and are given a " lump sum " award. But this award is regarded not as compensation for " injury " done, since simple tuberculosis is not an occupational disease, but as a payment for compulsory loss of employment. A miner can only obtain an award for simple tuberculosis if the condition is detected while he is at work or within a year after he has ceased underground work. No such limitation of time is applied to cases of silicosis or tuberculosis with silicosis.

2. In the system of awards of compensation in respect of *silicosis* the gradation in legal " stages " is applied solely to cases of " simple " silicosis, under which designation are included cases of the " tuberculo-silicotic " type which do not present evidence of active infection. The criteria adopted depend partly upon clinical considerations and partly upon the degree of incapacitation for work of the affected man. In the " ante-primary " stage there need be no incapacitation; the sole criterion here is the presence of the " earliest detectable specific physical signs of silicosis ". In the two later stages the physical signs must be " definite ", but the important consideration is the degree of incapacitation. This bears a general although not an exact relation to the degree of silicosis present.

In general it may be said that the " ante-primary " stage includes cases of a " slight " or of a " moderate " degree, as these terms are used in this paper; the " primary " stage includes " well-marked " cases fit for moderate physical work; the "secondary" stage includes "advanced" cases fit for light or no work. The three legal stages thus correspond closely with the stages of "simple" silicosis as described in this paper.

3. Since the onset of active tuberculosis in a silicotic subject is generally in itself sufficient to produce a "serious and permanent" incapacitation, the law prescribes that all cases of *tuberculosis with silicosis* shall be classed as being in the "secondary" stage, no matter what the actual degree of silicosis may be.

APPENDIX "A"

MINERS' PHTHISIS MEDICAL BUREAU

INITIAL
SPECIAL
PERIODICAL
BENEFITS.

"X"-RAY REPORT

Bureau No.......................

Board No. ....

Name..

Date.............................

CHAIRMAN'S NOTES.

Total Underground Service — Claimed	
Total Underground Service — Confirmed	
Machine drills	
Crushers, etc.	
Mining elsewhere	
Weight-index	
Chest-movement	
Pulse — Before exam.	
Pulse — After ,,	
Capacity for work	
Remarks	

Initials of Radio-grapher.	No.	The Skiagraph shows:—
	1	Normal Thorax.
	2	Rather more Fibrosis than usual.
	3	More Fibrosis than usual.
	4	Commencing generalised Fibrosis.
W. S.	5	Moderate generalised Fibrosis.
	6	Well-marked Fibrosis.
	7	Very well-marked Fibrosis.
	8	Gross Fibrosis.
W. S.	9	Fibrosis, ~~partly~~/mainly SILICOTIC in type.*
	10	Fibrosis partly/mainly INFECTIVE in type.*
	11	Appearances suggestive of TUBERCULOSIS RIGHT/LEFT lung.
W. S.	12	Apparently definite TUBERCULOSIS ~~RIGHT~~/LEFT lung.
	13	Peribronchial thickening.* Hilus thickening.*
	14	Pleural thickening RIGHT/LEFT side.
	15	Pleural effusion RIGHT/LEFT side.
	16	Consolidation RIGHT/LEFT side.
	17	Heart asthenic,* vertical* in type.
	18	Heart enlarged.
	19	Aorta enlarged.* Aortic aneurysm.*
	20	Other changes, viz.

* Delete terms not applicable.

Macroscopic Appearances in Silicosis

SIMPLE SILICOSIS[1]

FIG. 1. — Moderate degree of simple silicosis. The lung shows considerable excess of pigmentation, with moderately numerous "small" to "medium" sized palpable silicotic nodules. (Cf. fig. 7 and film 9.)

FIG. 2. — Very well-marked degree of simple silicosis, with "large" miliary nodulation. (Cf. fig. 8 and film 13.)

[1] Figs. 1 to 4 are taken from the lungs of European miners.

FIG. 3. — Very well-marked degree of silicosis, with many large irregular nodules and some areas of fibroid consolidation. No overt tuberculosis.

FIG. 4. — Very extensive tuberculo-silicotic consolidation, without overt tuberculosis. There is marked emphysema, and emphysematous bullae are visible at the marginal portions of the diaphragmatic surface of the lung.

TUBERCULO-SILICOSIS IN LUNGS OF NATIVE MINE LABOURERS

These photographs illustrate the more grossly infective type of tuberculo-silicosis which is more characteristically seen in certain cases of the disease occurring amongst native mine labourers.

FIG 4 A. — Very extensive tuberculo-silicosis in lower lobe, with active tuberculosis. Complete destruction of upper lobe. Lung of a native mine labourer.

FIG. 4 B. — Very extensive dense fibroid consolidation of tuberculo-silicotic character, with tuberculous cavitation in upper lobe. Lung of a native mine labourer.

Microphotographs on Uniform Scale (1 × 9)

(To illustrate the Scale of Lesions in Silicosis)

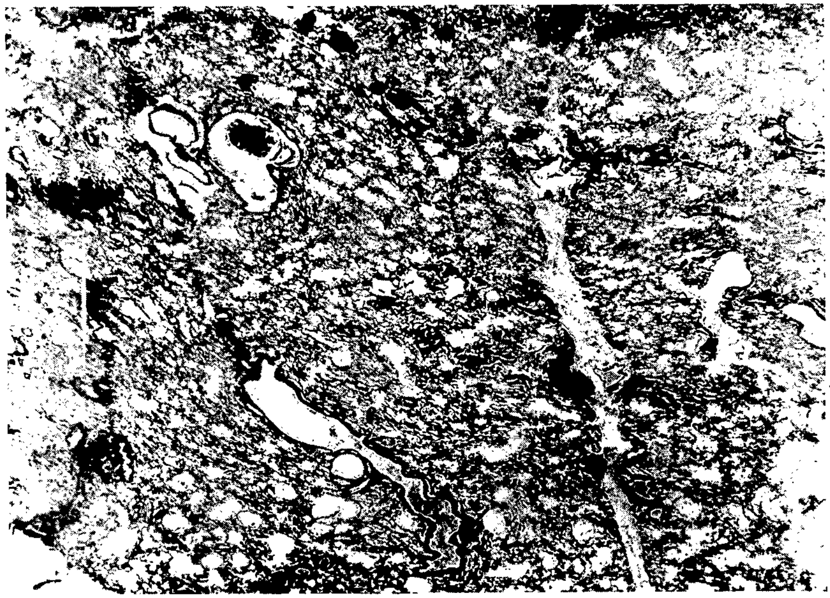


FIG. 5. — Condition corresponding to most radiographs of "Commencing Generalised Fibrosis". There is some excess of pigmentation, with one or two minute foci of fibro-blastic reaction. Bronchiolitis is present. The lung is congested.

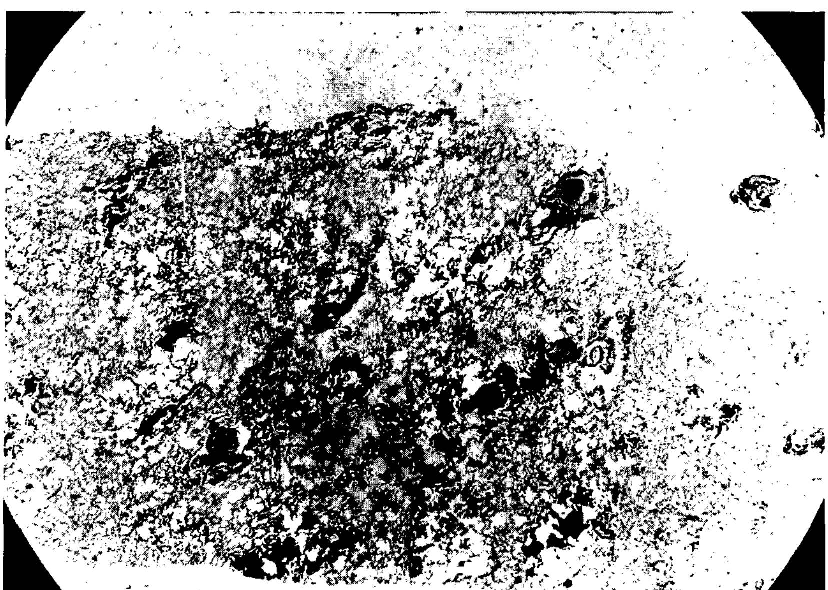


FIG. 6. — Slight degree of simple silicosis, with "small" miliary nodulation. The nodules shown are just palpable; there is no necrosis.

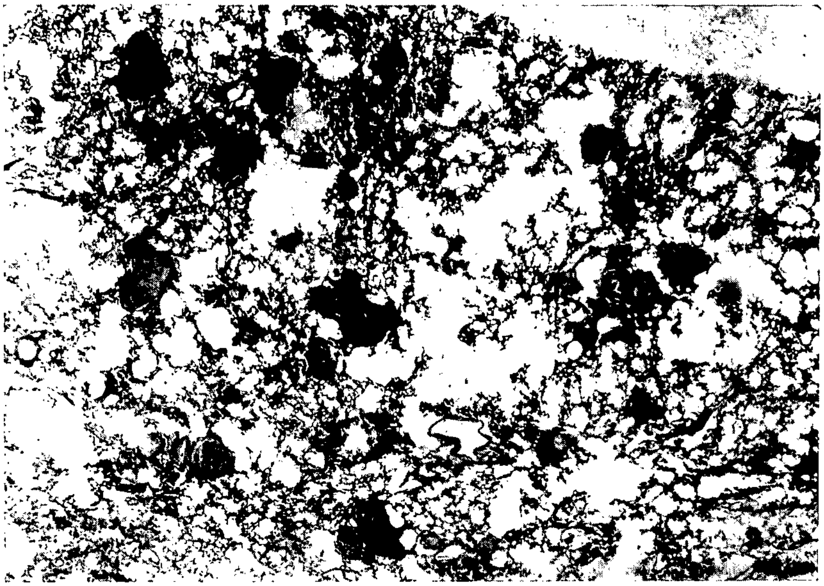


Fig. 7. — " Moderate " degree of simple silicosis. " Small " and " medium " sized nodules; the composite character of most of the latter is well seen; none show necrosis. There is some amount of emphysema, and the lung is congested. (Cf. fig. 1 and film 9.)

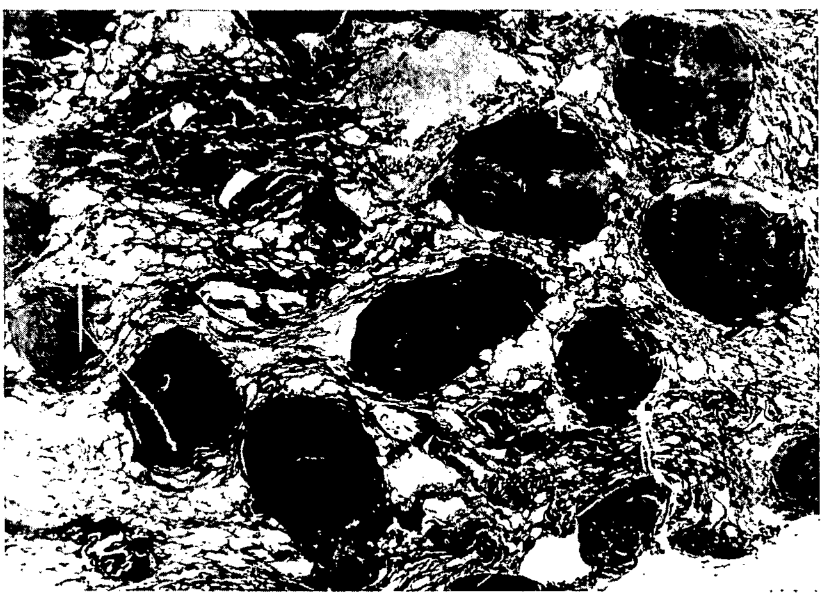


Fig. 8. — " Very well-marked " or " advanced " degree of simple silicosis. The section shows a cluster of " large " nodules of silicotic type. Most are of composite structure: none show necrosis. (Cf. fig. 2 and film 13.)

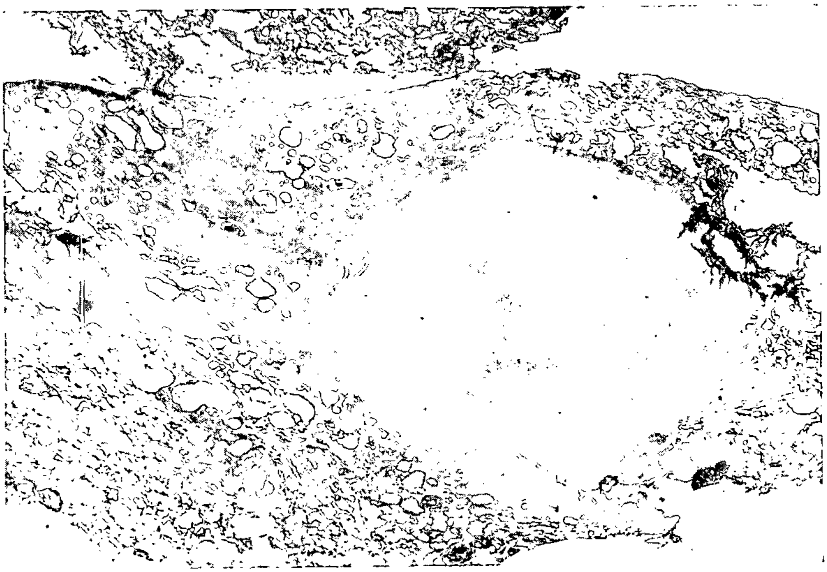


Fig. 9. — Tuberculo-silicosis. " Very large " isolated tuberculo-silicotic nodule, with massive necrosis.

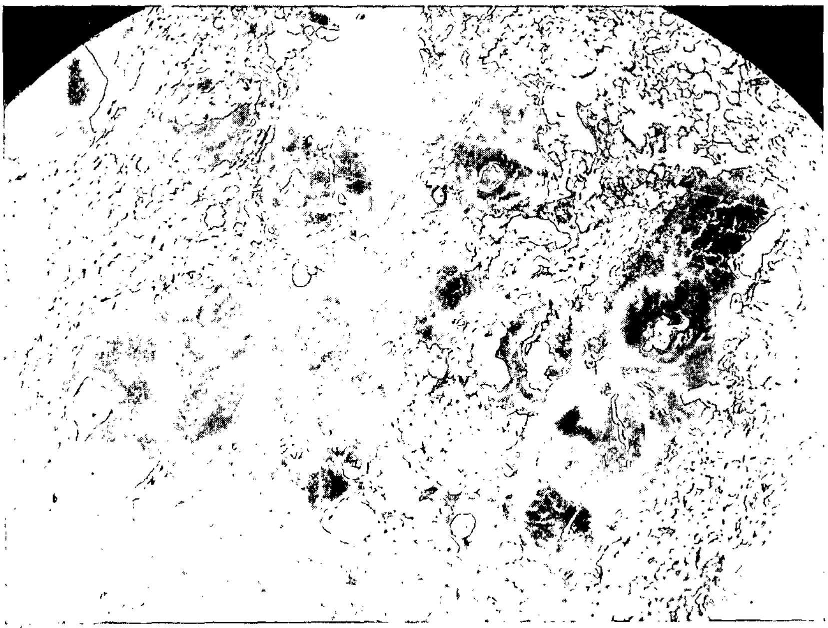


Fig. 9 a. — Infective nodules associated with slight degree of silicosis. The silicotic islets are small and are embedded in limited areas of tuberculous infection.

FIG. 10. — Tuberculo-silicosis. Section from an area of massive tuberculo-silicotic consolidation. Foci of active tuberculosis are present.

Physical Types in Silicosis

THE ROBUST TYPE

FIG. 11 A.

FIG. 11 B.

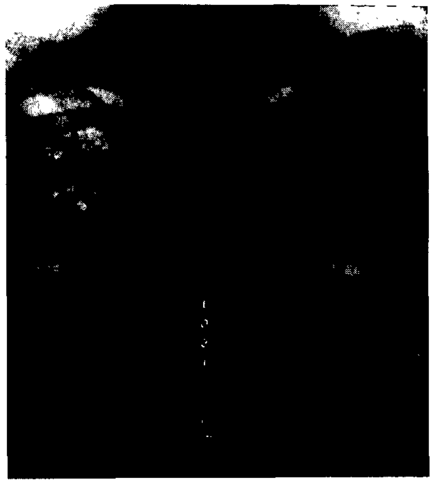


FIG. 11 A. — Photograph of case of advanced silicosis in elderly man of originally robust type. Note the characteristic "semi-emphysematous" conformation of the chest and the tendency to obesity which is common in this type of case.

FIG. 11 B. — From a radiograph of his chest. This man is still actively engaged as a surface mine official. He was first found to have silicosis over twelve years ago.

FIG. 12 A.

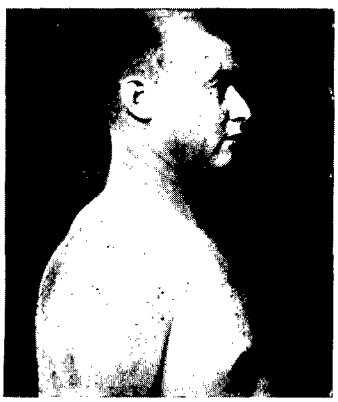


FIG. 12 B.

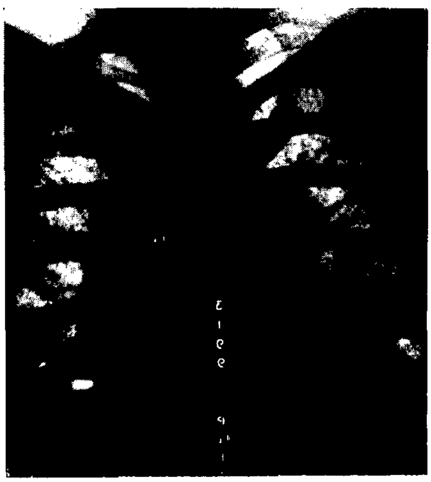


FIG. 12 A. — Photograph of well-marked case of simple silicosis in individual of originally robust type. His radiograph, FIG. 12 B, shows a well marked silicosis of the "classical" type. This man is still actively engaged as a senior underground official, and states that he is as well as ever; he plays golf and goes shooting when on holiday. He was first certified to have silicosis eight years ago.

THE PHTHINOID TYPE

FIG. 13 A.

FIG. 13 B.

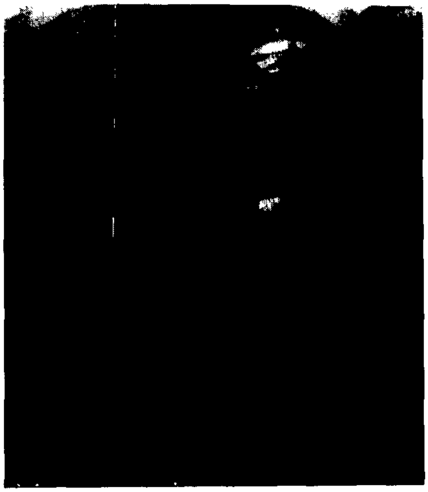


FIG. 13 A. — Photograph of well-marked case of tuberculo-silicosis in originally phthinoid type of man.

FIG. 13 B. — A print of his radiograph. It shows bilateral sub-apical consolidation, the appearances being those of a fibroid phthisis. The lesions have remained stationary for at least five years. He is in fair but not good health, but is still engaged in fruit farming. He was first found to have silicosis eleven years ago; he was then a highly placed mine official. (Film 18 is also taken from this case.)

FIG. 14 A.

FIG. 14 B.

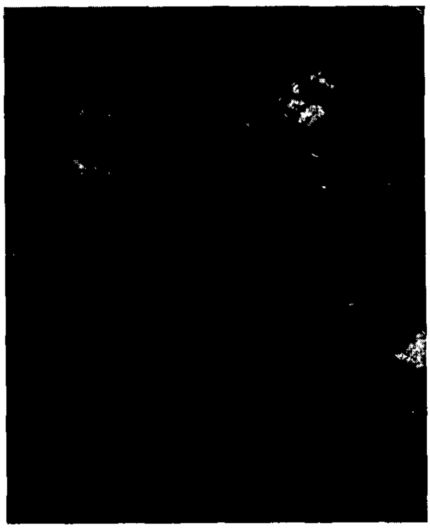
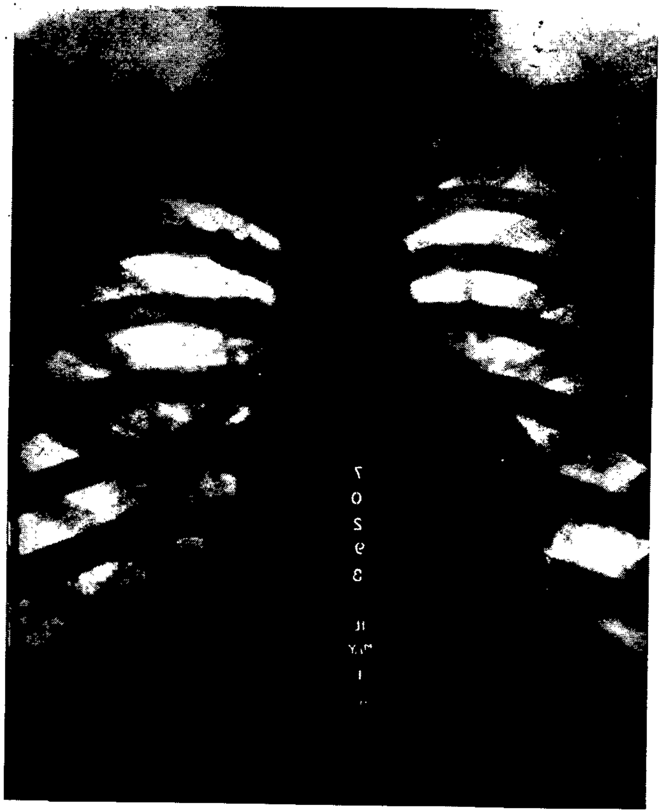


FIG. 14 A. — Photograph of case of moderate silicosis in an initially phthinoid type of man.

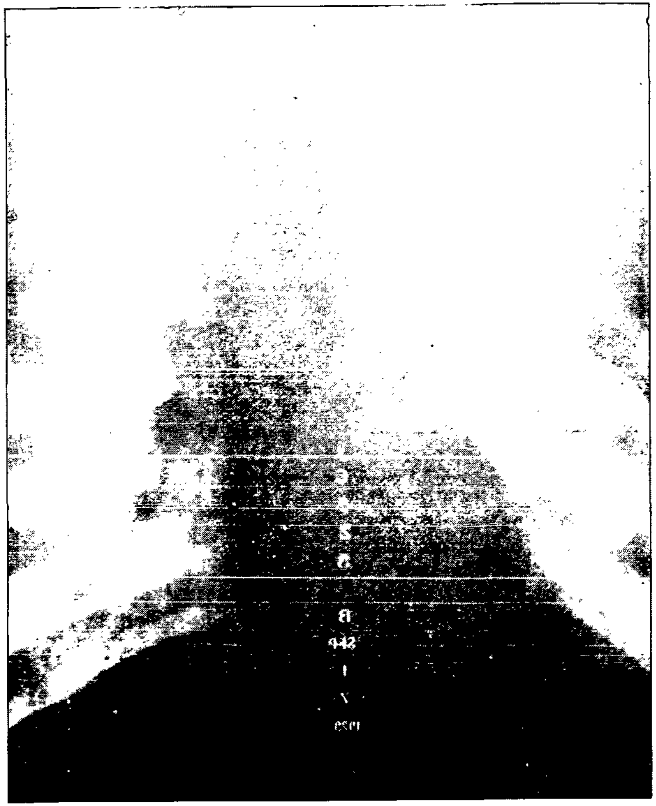
FIG. 14 B. — A print of his radiograph, which is of infective type. This man is quite healthy, but short of wind; he is employed as an assistant storekeeper. He left underground work twenty-one years ago.

Series of Radiographs to Illustrate the Radiology of Silicosis

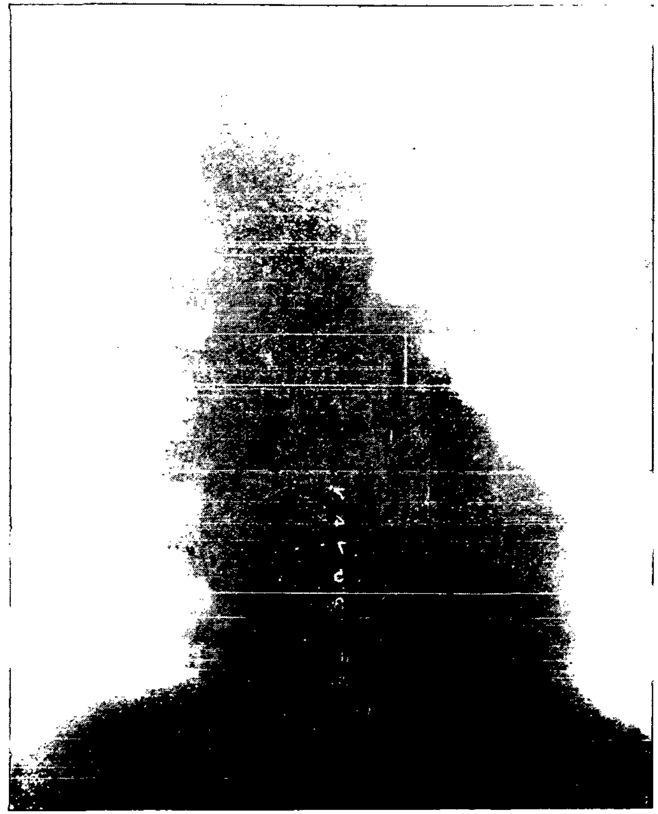


Film No. 1. — Normal Thorax.

Film No. 2. — Rather More Fibrosis than Usual.



Film No. 3. — Rather More Fibrosis than Usual, partly Infective in type.



Film No. 4. — More Fibrosis than Usual.

Film No. 5. — More Fibrosis than Usual, partly Infective in type.

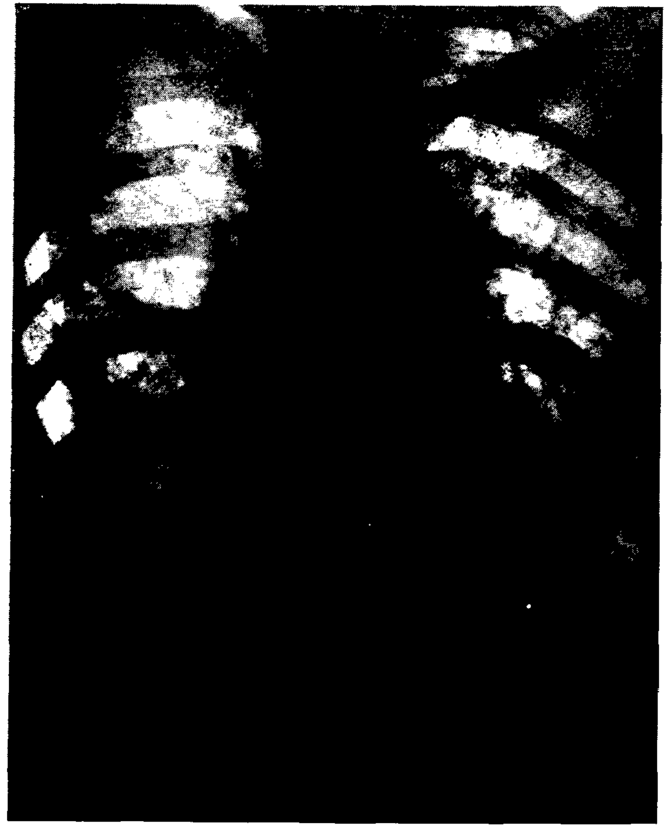
Film No. 6. — Simple Commencing Generalised Fibrosis.

Film No. 7. — Commencing Generalised Fibrosis, partly Silicotic in type. Characteristic film of slight degree of Silicosis.

Film No. 8. — Commencing Generalised Fibrosis, partly Infective in type.

XIII

Film No. 9. — Moderate Generalised Fibrosis, Silicotic in type. Moderate degree of Silicosis. (Cf. figs. 1 and 7.)

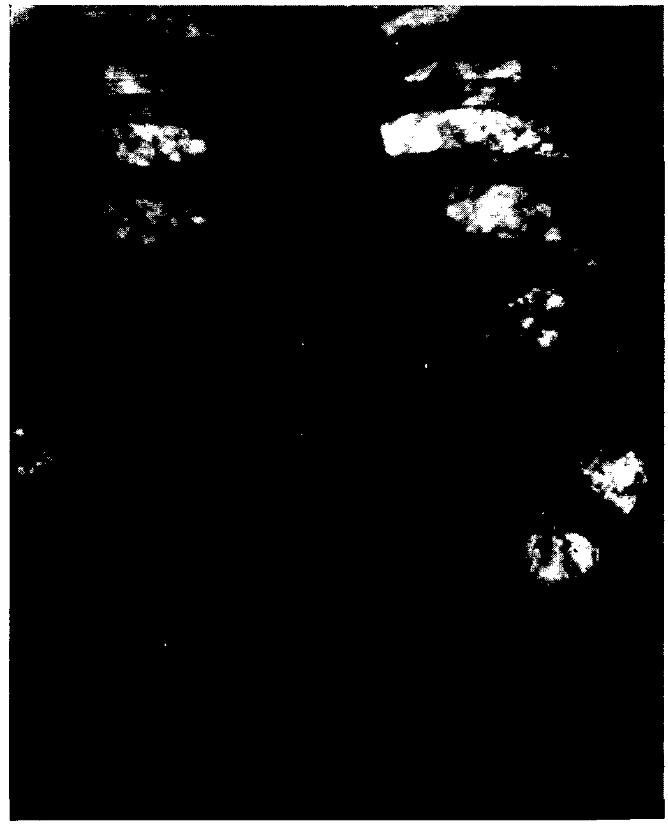


Film No. 10. — Moderate Generalised Fibrosis, partly Infective in type.

FILM No. 11. — Well-marked Fibrosis, Silicotic in type. Well-marked degree of Silicosis

FILM No. 12. — Well-marked Fibrosis, partly Infective in type.

Film No. 13. — Very well-marked degree of Fibrosis, Silicotic in type. Very well-marked Silicosis. (Cf. figs. 2 and 8.)



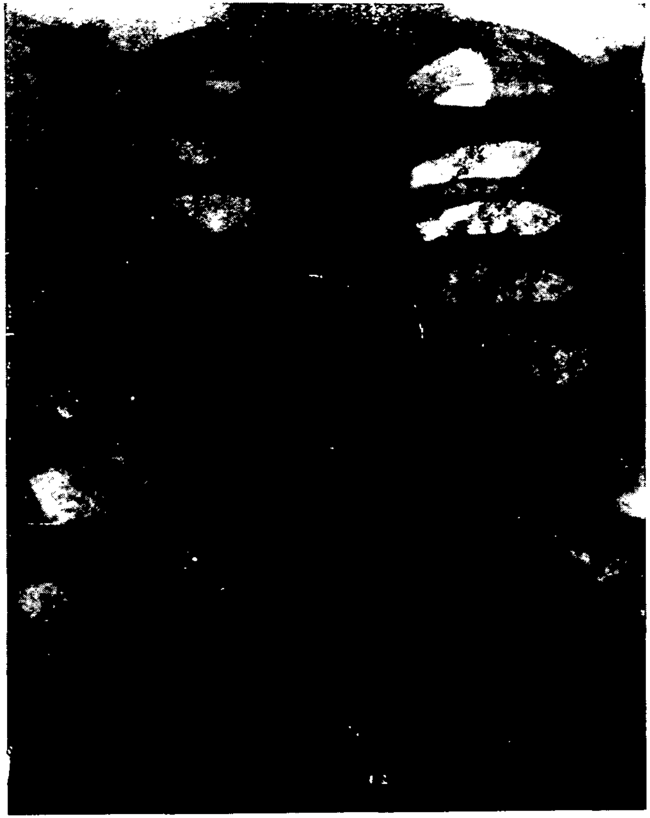
Film No. 14. — Very well-marked degree of Fibrosis, partly Infective in type.

FILM No. 15. — Gross Fibrosis, Silicotic in type. Advanced Silicosis.

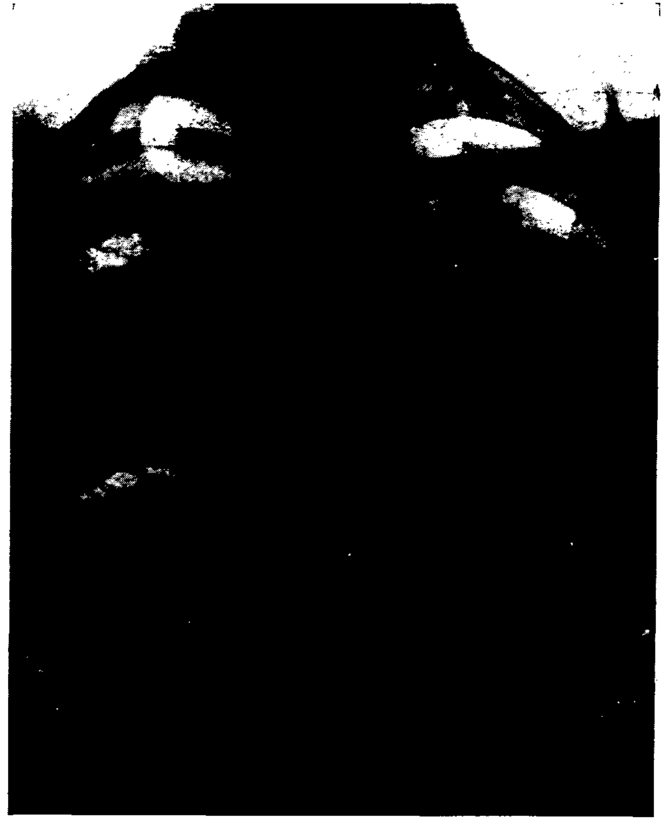
FILM No. 16. — Gross Fibrosis, partly Infective in type.

Film No. 17. — Well-marked Silicosis, with general Calcareous Deposit in nodules.

Film No. 18. — Case of very chronic Tuberculo-silicosis. The lesions shown have remained stationary for five years.

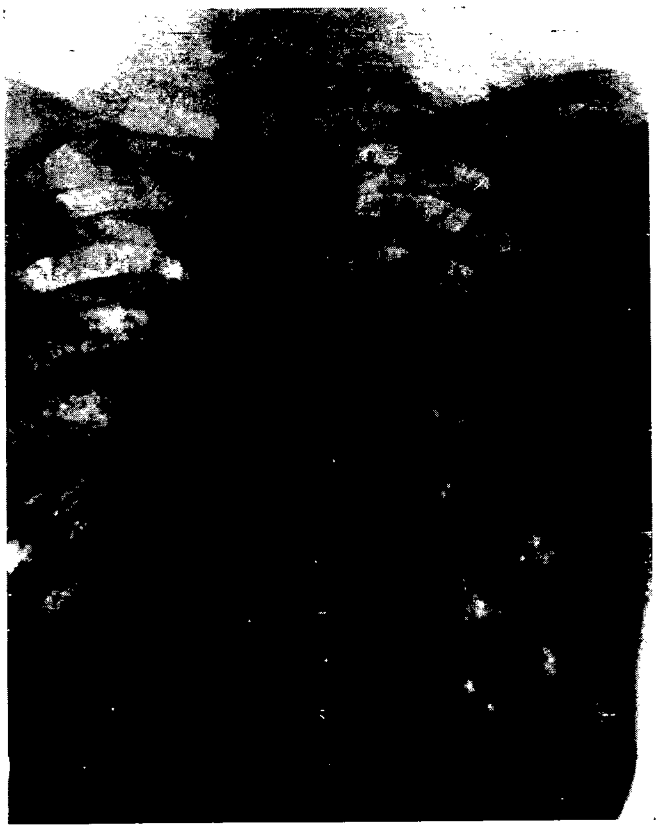


FILM. No. 19. — Moderate degree of Silicosis with Tuberculosis.

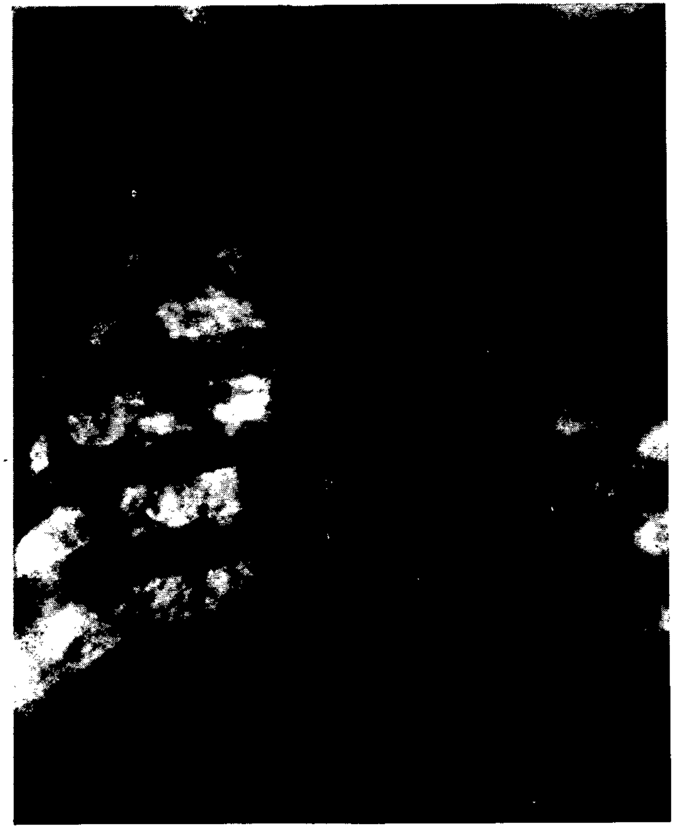


FILM No. 20. — Well-marked degree of Silicosis with Tuberculosis.

XIX



FILM No. 21. — Very well-marked degree of Silicosis with Tuberculosis or Tuberculo-silicosis. (Cf. fig. 3.)



FILM No. 22. — Advanced Silicosis with Tuberculosis, or Tuberculo-silicosis.

SILICOSIS IN AUSTRALIA

BY KEITH R. MOORE, M.B., B.S., D.P.H., DIRECTOR, DIVISION OF INDUSTRIAL HYGIENE, COMMONWEALTH DEPARTMENT OF HEALTH, AUSTRALIA

The rapid increase in the population of Australia which marked the latter half of last century was due in great part to the discovery in several parts of the Continent of rich alluvial gold fields. A large proportion of the migrants of this period came from mining districts in England and other countries.

The resultant stimulus to prospecting brought about the discovery of other metalliferous deposits, and to-day many of the Australian mining fields bear names such as Bendigo, Broken Hill, Kalgoorlie, which are almost household words.

The conditions under which deep mining was carried out in the earlier days exacted a heavy toll of lives from those who were connected with the industry. The advent of modern procedure involving the use of water in drilling and more meticulous attention to ventilation, dust prevention and the regulation of blasting has doubtless resulted in saving many lives. Silicosis has been demonstrated in many of the mining fields and a high death-rate from pulmonary diseases, including tuberculosis, has been evidenced in association with the industry. The following table shows the increase in mortality from phthisis during the development of the mining industry in the Bendigo district:

ANNUAL MORTALITY FROM PHTHISIS PER 10,000 OF POPULATION AMONGST MALES AGED 21 AND UPWARDS

Period	Bendigo and district	Victoria
1870-1872	35.33	22.15
1880-1882	60.44	26.89
1890-1892	77.90	26.37
1900-1902	77.36	23.18
1903-1905	62.29	20.81

The following table shows the mortality in the occupational group, mining and quarrying, as compared with the average general mortality during the years 1908-1914. These figures are taken from a table published by the New South Wales Board of Trade in 1919:

State	Average number of mining employees	Average number of deaths per year	Death-rate per group	Annual death-rate per 1,000 population
New South Wales	37,715	593	15.7	13.9
Victoria	16,363	508	31.0	27.5
Queensland	13,586	282	20.7	18.5
South Australia / Northern Territory	6,614	84	12.7	11.2
Western Australia	16,118	218	13.5	12.0
Tasmania	5,662	58	10.2	9.1
Commonwealth	96,058	1,743	18.2	16.1

New South Wales

Investigations and Enquiries

During the reticulation of Sydney with a system of sewers attention was focussed on the conditions under which the men were working, and a Sewer Works Ventilation Board was appointed in 1902 to enquire into the working conditions and to recommend, where possible, any means of improvement whereby the work might be rendered less hazardous.

The principal country rock on which Sydney stands is sandstone containing over 90 per cent. of silica.

The Board found that " for many years past miners employed on this class of work (tunnelling) suffered acutely from a disease which was for a long time known by the rather misleading term ' sewer disease ', but as the complaint became more widely known it was strongly suspected that dust was the chief cause of the mischief ".

The Board blamed the fumes of explosives and the expired air from the lungs of the miners in tunnels, imperfectly ventilated, as causes contributory to the high mortality, but stated that the dust from hammering, drilling and the use of the pickaxe was probably the sole cause of the disease once known as " sewer disease ".

The first recommendation of the Board was the prevention of dust. Next, efficient ventilation was recommended and suitable change-house accommodation. The work of a sewer miner in tunnelling sandstone was regarded by the Board as a dangerous occupation and a day of six hours was recommended for these men.

In 1907 another Committee was appointed in Sydney to enquire and report on methods of excavation in trenches and tunnels through sandstone where blasting operations are limited or not permissible, and as to whether the methods in use might be improved and made less dangerous to the workers by the use of rock-cutting or boring machinery. The terms of reference of this Committee also included an enquiry into rates of pay and hours of work.

The Committee reported that the best method of preventing diseases from dust would be the introduction of machinery. Six hours were recommended as a day's work, and it was also recommended that £500 should be made available for experiments with rock-cutting machinery. Exhaust ventilation was advised in place of forcing air to the working face.

In 1912 a reported epidemic of pneumonia at Broken Hill was investigated by Armstrong, who reported that the death-rate from pneumonia among underground miners in that locality during 1910-1912 was 6.5 per thousand or nearly four times as great as that for all males in New South Wales. The death rate from pneumonia for females in Broken Hill was only slightly higher than that for females in the rest of the State.

In 1914 a Royal Commission was appointed to enquire into the mining industry at Broken Hill. With regard to industrial diseases, this Commission stated that pneumonoconiosis and plumbism were among the risks of a miner's calling, while other diseases—for example, pneumonia—were added risks of the calling, but not strictly industrial because they affected others than miners. From unanimous medical testimony the Commission concluded that pneumonia was more prevalent, severe and fatal, among miners in Broken Hill than in any other class in the State. While attributing sudden changes in temperature as the prime cause, the Commission advanced the opinion that dust inhalation in any form would predispose to the disease.

This Commission expressed the opinion that pneumonoconiosis was practically unknown at Broken Hill and blamed mining in other States for such cases as had been noted. Tuberculosis was a disease to which the Broken Hill miners, as elsewhere, were peculiarly subject, and the presence of tuberculous patients in a mine was considered particularly dangerous.

This Commission recommended exclusion from mines of men suffering from tuberculosis or pneumonoconiosis, medical examination prior to employment, compensation of sufferers from pneumonoconiosis or tuberculosis, and that the dependants of the latter should be a charge on the State.

In 1916 a forty-four-hour week was granted by the Commonwealth Court of Conciliation and Arbitration for underground men at Broken Hill, largely on account of the association between working conditions and the incidence of pneumonia and tuberculosis.

In 1919 the New South Wales Board of Trade, in response to a request by the Government, after reviewing the available information concerning pneumonoconiosis, concluded that, while there was an undue mortality from pulmonary disease in the case of stone masons and sandstone quarrymen working on stone containing free crystalline quartz, there was not sufficient evidence to form an opinion as to the prevalence of these diseases among miners, and recommended that a Technical Commission of Enquiry be constituted to ascertain the actual facts, " using clinical and radiological means ". As a result of this recommendation, in December 1919 a Technical Commission was constituted to examine the miners at Broken Hill. This Commission, for the first time in Australia, used X-rays as a means of diagnosis of silicosis as an occupational disease.

In its preliminary report the Commission records the results of examination of 4,337 mine employees. In 370 of these, the examinations were incomplete. Of the total, 193 cases of pneumonoconiosis were diagnosed, 90 in the first stage, 44 in the second and, in 59 cases, complicated with tuberculosis. In addition, 39 cases were definitely diagnosed as suffering from pulmonary tuberculosis only, and in a further 26 it was thought " highly probable that these persons were suffering from uncomplicated pulmonary tuberculosis ".

The Commission defined the stages of pneumonoconiosis on which the diagnoses were founded as follows:

> A person in the first stage of the disease shows no impairment of his working capacity and of his general health. The photographs taken with the X-rays show the presence of an early fibrosis in the lungs.
>
> A person in the second stage exhibits a more advanced fibrosis in the X-ray photographs and in some individuals clinical evidence of the presence of the disease.
>
> In the third form, radiographic and clinical evidence of infection with tuberculosis is present.
>
> Tubercular infection may supervene in either the first or second stage of pneumonoconiosis.

The Commission found that pneumonoconiosis arises in Broken Hill as a result of inhalation of dust among those persons who have been engaged in drilling and blasting underground and concluded that " pneumonoconiosis arising as a result of work in Broken Hill only progresses so slowly that no impairment of working capacity occurs previous to infection with tuberculosis ".

The Commission recommended exclusion from the mines and compensation of all persons suffering from tuberculosis; also that no person suffering from pneumonoconiosis should be allowed to continue working on the mines. The reasons given for the last-mentioned recommendation were: increased liability of such persons to tuberculosis and pneumonia, and other pulmonary diseases will be more severe and more fatal; such persons should follow an open-air occupation, agricultural or pastoral, and will thus be brought less frequently into contact with other persons and less often exposed to tuberculous infection; they should be kept under observation and a scheme for employment prepared.

In a further report in 1922 on 6,538 miners, the Commission stated that the form of pneumonoconiosis found at Broken Hill is characterised by changes along the air passages and beneath the pleural covering of the lungs and by scanty affection of those parts directly concerned with respiratory exchanges. This form of pneumonoconiosis was stated to differ from those found among miners at Bendigo, Cobar and Kalgoorlie, and among rock-choppers in the Sydney sandstone.

Of 2,618 underground men examined, 266 showed pneumonoconiosis, 113 in the first stage, 51 in the second stage, and 102 complicated by tuberculosis; 107 additional men were diagnosed as suffering from tuberculosis only.

As a result, two Special Rules applying to the Broken Hill district were incorporated in the Mines Inspection Act of New South Wales regulating firing as far as possible to the end of shift, and requiring the moistening of ore being filled or moved in any working place, to prevent the escape of dust.

A Bureau of Medical Inspection was established to follow up the work of the Commission by examination of applicants for employment under the Workmen's Compensation (Broken Hill) Act, 1920.

Dr. S. A. Smith, of the Technical Commission, later analysed certain important features of the relationship between pneumonoconiosis and tuberculosis.

He found that of 8,966 men examined, 322 showed changes due to dust; of these, 148 or 46 per cent. suffered from tuberculosis.

Of the remaining 8,644 who showed no changes due to dust, 161 or only 2 per cent. suffered from tuberculosis.

Of the 177 men showing simple fibrosis the subsequent history was followed for two and a half years and resulted as follows:

Place	Total number	Number who developed tuberculosis
Broken Hill	101	27
Adelaide	19	7
Melbourne	6	–
Sydney	2	–
Ballarat and Bendigo	3	1
Newcastle	1	1
Griffith	34	1
River and Country	11	–
Cities	132	36 (27 per cent.)
Country	45	1 (2 per cent.)

Dr. Smith concludes that " changes in the lungs due to inhalation of mine dust produce a definite susceptibility to the development of pulmonary tuberculosis; that the development is most frequently not an activation of an old lesion but a new infection, and that the frequency of infection is proportional to the number of persons with whom the affected worker is daily brought in contact ".

As a matter of interest, it may be mentioned here that the Broken Hill silver-lead lode was discovered in 1883 and still represents the main source of Australia's lead production, supporting a town of 17,000 inhabitants as well as the township of Port Pirie comprising a further 13,000 inhabitants. At this port the Broken Hill ore is smelted and the pure lead and other metals obtained. Mining operations are at present carried out to a great extent in sulphide ore which is sparsely intermixed with a gangue of rhodonite, a manganese compound with a low free silica content. Analyses of the country rock at Broken Hill have shown the silica content, free and combined, to vary between 60 and 70 per cent., of which less than half is free silica.

Broken Hill now represents the only considerable metalliferous mining field in active working in New South Wales, although many miners are still employed in tunnelling and quarrying operations in Sydney, working in siliceous rocks, chiefly sandstone.

In 1922, the New South Wales Board of Trade, in conjunction with the Commonwealth Department of Health investigated clinically and radiologically the prevalence of pulmonary diseases amongst workers in sandstone and other siliceous rocks in the metropolitan district of Sydney. Of 716 men examined, 123 were found to be suffering from silicosis. Using the standards set down by the Broken Hill Commission, 47 of these were diagnosed as being in the first stage, 38 in the second and 38 were stated to be suffering from pneumonoconiosis complicated by tuberculosis. In 16 men, pulmonary tuberculosis only was diagnosed.

In 1927 Dr. Charles Badham drew attention to a series of cases in which the X-ray films showed a very fine type of fibrosis (*Report of Director-General of Health, New South Wales*, 31 December 1927, p. 102). These cases came from tunnels around Sydney where the country rock contains a high proportion of combined silica. Dr. Badham considers that the fibrosis probably differs from true silicosis and suggests the term " Silicatosis " for such cases.

Standards of Mine Ventilation

The Broken Hill Technical Commission in its report of 1922 regarded ventilation as the most important factor in the removal of dust from the mines, and stated as its opinion that an air current exceeding 20 feet per minute was sufficient to keep the suspended dust below the quantum necessary to give rise to pneumonoconiosis. While this amount of air movement was not obtainable in large stopes, it was recommended that the working of mines be laid out to ensure as far as possible an air velocity of 20 feet per minute. Dependent on the dilution of the concentration of dust by a large volume of air, the Commission found that the passage of 5,000 cubic feet a minute past any working place would be sufficient to prevent the accumulation of dust in the air during the conduct of mining operations, except in the immediate neighbourhood of drilling operations without adequate water supply or where heaps of dry ore were being shovelled. The Commission stated that water must be used to assist ventilation in keeping down dust in these operations.

In 1924, Dr. Badham considered that 60 linear feet of air-movement per minute were necessary to keep the dust content low. He prescribed a standard of 200 dust particles per cubic centimetre for sandstone tunnelling and said that this " could in all well-ventilated works be halved ". Dr. Badham used the Owens' dust sampler in his work, checking his results by gravimetric methods.

Legislation

In 1920 a Workmen's Compensation (Silicosis) Act, 1920 (No. 13 of 1920), was passed in New South Wales to amend the Workmen's Compensation Act of 1916. The purpose of this Act was to enable the provision of a scheme of compensation to be paid by the employers to workmen certified to have suffered death or total disablement from fibroid phthisis or silicosis of the lungs, or from that disease complicated by tuberculosis or from any other pulmonary disease caused by exposure to silica or other dust, also to those men who though not totally disabled are found on medical examination to be suffering from any of the above diseases to such an extent as to make it dangerous to continue work in the industry. This Act applied to any man engaged in work involving exposure to silica dust, who had been continuously resident in New South Wales during five years immediately preceding the date of death or incapacity and who had been employed as specified for not less than three hundred days during that period, or to men who had been resident for five years out of seven and had been employed for at least five hundred days in that period.

Under this Act was produced in 1927 the Workmen's Compensation (Silicosis) Scheme No. 1, applying to stonemasons, quarrymen, rock-choppers and sewer miners in the Sydney area who are eligible under the residential and employment qualifications mentioned above, and who have been certified in accordance with the conditions prescribed in the Act.

Under this scheme the question of the award, amount and apportionment of compensation rests with the judgment of a Joint Committee appointed by the Minister under the scheme. Provision is made for the immediate payment of compensation by the employer in accordance with the general rate for the State in the case of death or total disablement and, where men are suspended from work owing to silicosis, but not totally disabled, for the payment after two weeks of a sum which will supplement, if necessary, his earnings making them equal to his previous earnings. This sum is paid from a general fund maintained by subscriptions from the employees, and which may be subsidised from time to time by Parliamentary vote. The subscriptions are fixed and levied as necessary by the Minister and the fund is administered by the Joint Committee. Provision is made under this scheme for the payment of lump-sum compensation, and the appointment of medical authorities for periodical examination and certification. The onus for arranging preliminary medical examination is thrown on the employer, and the workman is obliged to submit himself for periodic and other examinations, to give the necessary true information in respect of his employment and not to re-engage in any industry affected by the scheme after suspension.

Employees in the mining industry at Broken Hill come under a special Act known as the Workmen's Compensation (Broken Hill) Act, 1920 (No. 36 of 1920), which is also construed with the Workmen's Compensation Act, 1916. This Act includes a scheme known as the Broken Hill Mines (Pneumonoconiosis-Tuberculosis) Compensation Scheme.

The present medical authority under this scheme is appointed in Broken Hill by the Minister and includes the medical officer in charge of the Bureau, which has been in operation since 1922. Prior to the introduction of the scheme which is similar in details of operation to the Silicosis Scheme No. 1 described above, the Technical Commission of Enquiry represented the authority.

Victoria

General

The history of metal mining in Victoria is concerned mainly with gold, which was discovered on four large alluvial fields between July and December 1851. Of these fields the only one in which there has been any activity of recent years is Bendigo. Deep mining was commenced in this place shortly after 1870. The country rock consists of quartz, slates and sandstones with a high silica content. The field at present is in a very low state, less than a hundred men working underground where formerly there were thousands. At one time there were fifty-three shafts in operation, over 2,000 feet deep and several over 4,000 feet, the deepest reaching 4,614 feet.

The Ballarat field in which lode mining was formerly practised, although at no great depth, has been closed down for many years.

Investigations and Enquiries

In 1907 Summons submitted a report on miners' phthisis to the Committee of the Bendigo Hospital, stating that there was undue mortality among Bendigo miners and that this was due to respiratory diseases, notably tuberculosis. He classified the cases examined according to two clinical types:

1. A pure fibrosis of the lungs, non-tuberculous in origin, which is silicosis.
2. The mixed type with a tuberculous infection in a fibroid lung.

Of those affected with either type, 47 per cent. had specific bacilli in the sputum. Summons stated that " although only 47 per cent. of cases are infected, all miners dying of lung complaint die of tuberculosis ".

No further work of this nature was undertaken in Victoria until 1920, when D. G. Robertson investigated clinically the conditions amongst miners in Bendigo. He found the incidence of tuberculosis higher in Bendigo than in the rest of the State, and attributed this to the presence of old miners affected with pulmonary disease. A compensation scheme was recommended.

In 1928 the Commonwealth Department of Health conducted an investigation into the health and working conditions of employees in the metal-mining industry in Victoria and Tasmania at the request of the Commonwealth Court of Conciliation and Arbitration. In Bendigo sixty-one men were examined radiologically and clinically, representing 37 per cent. of the total metalliferous mine employees in the district. Among underground workers 9.4 per cent. were diagnosed as suffering from silicosis uncomplicated and a further 7.5 per cent. from silicosis and tuberculosis. Of all workers, 3.3 per cent. were found to be suffering from tuberculosis only.

Mine Ventilation

In 1906 Summons stated that it is "unnecessary to demand that a fixed volume of air be supplied to the working faces for the quantity is only a means to produce the quality and to maintain less than 0.15 per cent. of carbon dioxide in the air ".

The investigation by the Commonwealth Department of Health in 1928, referred to above, included an examination of the working conditions. In respect of three mines visited at Bendigo it is noted that the temperatures ranged from 61° F. to 76° F. and the relative humidity averaged 88 per cent. The dry katathermometer cooling power averaged 4.9, a figure stressing the need for improvement in ventilation. The recommendations included in the report of the mining engineer who conducted these inspections stated that in all drives and cross-cuts over 100 feet, and rises and winzes over

30 feet in length or depth, artificial means of ventilation should be adopted unless bratticing is effectively carried out. Further recommendations include the supply of an extra hose for wetting heaps of broken ore when shovelling, special precautions for supplying water when " collaring " and against fogging from machines, and the restriction of firing to times at which the mine will be empty of workers.

Legislation

Industrial pulmonary diseases including tuberculosis are not included in the schedule of diseases for which compensation is paid in Victoria and no other legislation exists dealing with this subject.

The Mines Act, 1914, of Victoria contains the following clause relating to drilling: " No hole shall be bored or drilled by machinery underground unless a jet or spray of water shall be directed into and around such a hole. "

Queensland

General

Gold was first discovered in Queensland at Gympie in 1867. The country rock in this field consists largely of limestone, shales and slates. In 1872 the Charters Towers field was discovered, and in 1882 the Mount Morgan gold and copper deposit was found and has been worked practically up till the present day. The country rock at Mount Morgan consists of limestones, banded claystones and tuffs with quartz-porphyry dykes and sills and contains a fairly low silica content. Copper has been discovered at Cloncurry and mixed metallic deposits at Herberton and Chillagoe. All these fields are at present inactive, and the most active field at this time in Queensland is the Mount Isa silver-lead lode situated west of Cloncurry, far inland. The work at present in this area is wholly developmental.

Commissions and Enquiries

In 1911 a Royal Commission was appointed in Queensland to enquire into the working conditions in Queensland mines in relation to the health of the miners.

This Commission concluded that pulmonary fibrosis was not as common in Queensland as in Victoria and Western Australia, but that pulmonary tuberculosis appeared to be a relatively frequent cause of death among metalliferous miners in Queensland. Recommendations were made dealing with dust-prevention, ventilation and sanitation.

The Commission considered that miners suffering from pulmonary or laryngeal tuberculosis should be excluded from underground work, provided that means be taken to deal with the predisposing causes of infection among miners and among the general population, also providing that the difficulties in connection with the medical examination and the collection and distribution of funds be overcome in a reasonably economical manner.

Legislation

In 1915 the Queensland Government granted to mine employees suffering from pulmonary diseases a weekly allowance.

The Workers' Compensation Act, 1916 to 1926, of Queensland awards compensation for death or incapacitation from earning full wages at the work at which he was employed, as a result of certain industrial diseases. The list includes "silicosis of the lungs, miners' phthisis, pneumonoconiosis, pulmonary tuberculosis".

South Australia

Although in the past copper was mined extensively at Wallaroo and Moonta, the mining industry of this State is now very small and confined to a few scattered enterprises. No investigations or enquiries have been made dealing with the health of miners.

Industrial pulmonary diseases are not subject to compensation.

Tasmania

General

Although small in area this State is very rich in mineral resources. Gold has been mined in the Northern part of the island and tin-sluicing and mining is still carried on in the North-eastern part, but it is the West coast on which the larger mining operations are now practised. The two most important fields are at Mount Lyell and Rosebery. At the latter place an extensive zinc field is being developed around the site of two older mines, but relatively few men are employed here at present. At Mount Lyell a rich deposit of copper ore was first discovered in 1897. About 500 men are still employed underground here. The country rock is partly a conglomerate with quartzite pebbles embedded in a cementing matrix, and partly a schist. The silica content of the schist averages 60 per cent. and that of the conglomerate about 90 per cent. The ore contains about 63 per cent. silica, probably 50 to 60 per cent. in the free state.

Investigation

The only investigation into the health and working conditions of metalliferous mine employees in Tasmania was made in 1928 by the Commonwealth Department of Health. Reference has already been made to the Victorian portion of this enquiry.

In Tasmania the various mining centres were visited in turn and men examined clinically and radiologically practically at the mine-head. For radiological purposes a portable plant was used and was installed in the mine offices or in some suitable place close to the mine. At several mines the management permitted the men to undergo examination while on duty, and these men were brought to the surface during the working shift, examined and then returned to work.

In all, 650 mine employees volunteered for examination, comprising 65 per cent. of those available.

Of 314 underground employees, 5.9 per cent. were shown to be suffering from uncomplicated silicosis and 2.1 per cent. from silicosis with tuberculosis. Of all workers examined, 1.1 per cent. were found to be suffering from tuberculosis only, 1.2 per cent. in underground and 1.0 per cent. in surface workers.

Inspection of the industrial histories of examinees showed that there was a definite incidence of silicosis among those who had worked underground in Tasmania only, and also in Mount Lyell only, although in neither case was the incidence as high as that observed in Victorian mine employees. The incidence of tuberculosis, either alone or complicating silicosis, was found to be much lower in Tasmanian miners than in those examined at Bendigo.

Mine Ventilation

The working conditions in Tasmanian mines were inspected and form the subject of a portion of the report in the above investigation.

The temperatures recorded ranged from 47.5° F. to 69° F. and the average relative humidity was 92 per cent. The dry katathermometer cooling power averaged 7.1, indicating satisfactory ventilation. Dust counts made with the Owens' instrument and checked by a gravimetric method were on the average satisfactory, but unnecessarily high in some places.

The recommendations regarding mine hygiene quoted in the section dealing with Victoria apply also to Tasmanian mines.

Legislation

No industrial diseases are subject to compensation under Tasmanian law, although an Act was passed during 1929 [1] in an endeavour to provide miners disabled through industrial disease with a pension.

Western Australia

Gold was discovered at Northampton in Western Australia in 1842 and at Kimberley in 1882, but it was not till the discovery of the Coolgardie field in 1893 and the later discovery of the adjacent Kalgoorlie field that the mining industry of the State began to flourish. To-day many fields are in operation in various parts of this large State, employing over 4,000 men, about 3,000 of whom work in the famous " Golden Mile " between Kalgoorlie and Boulder City. The mines here are worked in some instances to a depth of over 3,000 feet in a country rock consisting of quartz diabases, calc-schists and acid amphibolites. An analysis of the dust collected in a dry-crushing mill and measuring less than 10 microns in diameter shows 43.58 per cent. silica. The approximate proportion of free quartz in this dust is 19 per cent.

Investigations and Enquiries

The Western Australian gold-mining industry has been the subject of more Royal Commissions than that of any other State.

The first of these was a Royal Commission appointed in 1905 to enquire into the ventilation and sanitation of the mines in Western Australia. This Commission expressed itself as unable to form an opinion as to the degree to which miners suffered from pulmonary disorders. Although only two cases of silicosis of local origin had been reported to the Commission, the local hospital returns showed that diseases of the respiratory system fell heavily upon miners.

[1] International Labour Office: *Legislative Series*, 1929, Austr. 2.

Assuming that the necessity for proper ventilation and sanitation was proven the Commission concerned itself with prescribing standards and procedures designed to secure efficiency in these.

The exclusion of persons suffering from tuberculosis of the respiratory organs from underground working was recommended, but not adopted, by the Government at that time.

In 1910 a Royal Commission was appointed to report upon pulmonary diseases among miners. The report of this Commission concluded:

> The miner is more liable to lung disease generally than the average male over fifteen years of age. The miner is less long-lived than the average male over fifteen, partly on account of greater liability to lung diseases.
>
> Tuberculosis of the lungs is on the increase among miners and is twice as prevalent as among all males over fifteen.
>
> Pneumonia among the acute, and bronchitis, asthma, emphysema and fibrosis of the lungs among the chronic, lung diseases are more prevalent among miners than among males over fifteen.

Mine employees were physically examined and the conclusion was drawn that fibrosis of the lungs could be detected amongst various groups of men in increasing percentages according to exposure to silica dust at work; also that exposure over comparatively long periods was necessary before the onset of recognisable symptoms. Machine mining and dry-treatment work were noted as prominent causes of fibrosis, especially machine work. Non-machine miners and truckers were found to be affected although to a less extent, and after much longer periods. Tuberculosis was not commonly found. The principle was laid down that " any man suffers from fibrosis to the extent to which he is exposed to the continued inhalation of mineral dust. If there be no dust, there will be no fibrosis, and conversely, the continued inhalation of dust certainly produces some fibrosis ".

The findings of the Commission prompted the appointment of another Royal Commission in 1911. This Commission found that " pneumonoconiosis without the super-imposition of other diseases of the respiratory organs had not yet attained very alarming proportions in Western Australia, and if the precautions suggested be carried out gold mining will become very little more injurious to health than other industries ".

Standards of procedure in respect of ventilation and dust prevention were prescribed and, for the first time in Australia, the recommendation was made that men suffering from tuberculosis or pneumonoconiosis be excluded from mine work, and in order to secure that this be effectively done, that every man should be medically examined before employment and all miners be medically examined at intervals of six months. The tuberculous person and his dependants were recommended as charges of the State and the pneumonoconiosis patients to be compensated under an insurance scheme.

In 1925 as a result of the recommendation of the above Commission, an arrangement was made by the Western Australian Government whereby the Commonwealth Department of Health made a complete physical and radiological examination of all metalliferous mine employees in Western Australia. This was carried out in Kalgoorlie at the Commonwealth Health Laboratory and in the surrounding country districts by a travelling unit equipped with a portable X-ray apparatus.

The following standards of diagnosis were adopted:

" Normal." — No evidence of pulmonary lesions due to dust, tubercle bacilli or any other cause.

" More fibrosis than normal." — Lung abnormality but not silicosis or tuberculosis.

Three types are recognised: (*a*) healed or inactive lesions not due to dust; (*b*) reticular markings accentuated as from arteriosclerosis, old age, auto-intoxication, high blood pressure or renal disease; (*c*) the same accentuated linear markings from dust. Dust other than siliceous may cause this but is not progressive. The appearance radiographically is of a fine network but without mottling. It should be noted, however, that where tuberculosis also is present these come under " silicosis plus tuberculosis ".

Subjects in this class were not reported under the Miners' Phthisis Act because: (i) the X-ray technique could not then secure uniformly reliable pictures; (ii) the same appearance was obtained in certain non-silicotic subjects; (iii) absence of symptoms; (iv) a clear definition was necessary of the group of cases coming within the meaning of the Act.

" Silicosis, early." — Fine mottling throughout; often breathlessness, cough and sputum; no physical signs.

" Silicosis, advanced." — Coarse mottling of the small " snowstorm " variety; often symptoms; phagocytic cells in the sputum containing dust; chest movements restricted in all movements; absence on inspection of the inspiratory bulging movement of the upper anterior part of the chest in the triangular areas between the lines joining the acromio-clavicular and sterno-clavicular joints and nipple on each side; dull to percussion; restricted air-entry and harsh broncho-vesicular murmur; rales often heard at bases.

" Silicosis plus tuberculosis " and " Tuberculosis only ". — Diagnosed on established clinical standards.

During 1925 and 1926 a total of 4,067 miners were examined. The results of this examination may be tabulated as follows:

	Number with silicosis	Per cent. of total	Silicosis plus tuberculosis	Per cent. of total	Tuberculosis only	Per cent. of total	Number examined
Surface workers	117	6.6	27	1.5	6	0.3	1,759
Underground workers	538	23.3	116	5.0	6	0.3	2,308
Total	655	16.1	143	3.5	12	0.3	4,067

Silicosis was not found in any case under forty years of age or with less than five years' underground work.

Since 1926 examinations have been made of the mine employees in Western Australia annually by the Commonwealth Department of Health. Of 2,290 men previously classed as normal in 1927, 30 or 1.3 per cent. were found on re-examination to be suffering from silicosis uncomplicated, and 13 or 0.5 per cent. from silicosis with tuberculosis. A further 3 or 0.2 per cent. had tuberculosis only. Of 491 diagnosed as silicotics, 86 or 17.5 per cent. showed silicosis with tuberculosis. In 1928, of 2,822 men classed as normal in the previous year, 48 or 1.7 per cent. had progressed to silicosis only, 11 or 0.4 per cent. to silico-tuberculosis, and 3 or 0.1 per cent. were found to be suffering from simple pulmonary tuberculosis. Of 425 silicotics, 25 or 5.9 per cent. showed signs of tuberculous complication on re-examination. In 1929, of 2,293 normals re-examined, 100 were diagnosed as silicotics. A further inspection of these cases, however, made it evident that the majority of these diagnoses were due to the introduction of improved plant and radiographic technique. It was considered that in only 26 or 1.1 per cent. of cases a definite advance had occurred in the disease.

Mine Ventilation

In 1905 the Royal Commission on the Ventilation and Sanitation of Mines laid down the first standards of air-composition for mines in Western Australia. This prescribed a maximum of 0.15 per cent. of carbon dioxide and a maximum temperature of 85° F. in any part of the mine.

When this subject was brought under consideration by the Royal Commission of 1911 no standards were recommended, the Commission considering that further enquiry on the subject was necessary.

Legislation

The first practical results of the recommendations of the Royal Commission of 1911 was the Miners' Phthisis Act of 1922 which was passed with the object of removing persons suffering from pulmonary tuberculosis from the industry, and the payment of compensation until suitable employment could be found for them. This Act was proclaimed on 7 September 1925, and provided that:

(*a*) Every person engaged in mining operations be required to submit himself when required to an appointed medical officer for examination;

(*b*) If on examination he is found to be not suffering from tuberculosis, he shall receive a certificate to that effect;

(*c*) If on examination he is found to be suffering from tuberculosis, the Minister may prohibit his employment in any mine;

(*d*) If on examination he is found to have developed definite symptoms of miners' phthisis uncomplicated by tuberculosis as to indicate that further employment in, on or about a mine may be detrimental to his future health, the Minister shall notify him accordingly.

Compensation for tuberculosis amounts to the ruling rate of pay in the districts in which the sufferer was employed at the time of prohibition of employment, until other suitable employment is found and offered by the Mines Department.

Under the Miners' Phthisis Amendment Act of 1925, if any prohibited person is or has become unable to work at any suitable employment, compensation as above shall cease to be payable, but such person shall be entitled to receive compensation not less than as prescribed by the scale of relief in force at the commencement of this Act, under the rules of the Mine Workers' Relief Fund, and similar compensation is accorded the dependants on the death of any such person.

SILICOSIS IN BELGIUM

BY DR. D. GLIBERT, BRUSSELS

The study of silicosis may even at the present time be said to have made very little progress in Belgium. Only the stage of establishing contact with this important problem has been reached, and the efforts of a few experts are at present concentrated in first of all bringing to the notice of medical circles knowledge of the results obtained in countries where for years back the question has been thoroughly investigated. It may be asserted that the question of the diagnosis of silicosis has so far hardly received the attention of the great majority of medical practitioners in our country.

As regards public opinion, almost complete ignorance reigns in regard to this matter. The workers' organisations themselves, representing as they do the most interested parties, would appear to show little or no concern in regard to the problem. At most a few articles have appeared in the daily political press, but this isolated effort has met with no echo.

In official administrative spheres action has consisted in the appointment of a non-official committee, but up to the present no really practical measure has been taken to obtain a comprehensive view of the subject.

This delay would appear to be due to several causes, the principal of which are as follows:

> The Government, and more particularly the medical factory inspectorate, has at its disposal neither radiographic installations nor the experienced staff required for this delicate research work.
>
> The extremely restricted credits granted are besides earmarked for definite purposes which exclude the possibility of the use of funds for effecting costly studies of this kind. It would be necessary, in order to form a well-grounded opinion on the subject, to examine a great number of patients, to have at one's disposal numerous radiographs, and in consequence to

involve relatively high expense. Nevertheless, thanks to special subsidies voted with a view to Government participation in the Liége Exhibition, the medical factory inspectorate has been able to make a certain number of radiographs which will be submitted to public view on the stands of the group designated "Social Insurance and Social Welfare". This will ensure effective propaganda amongst those best adapted to profit by a knowledge of the question.

The obstacles referred to above, however, are far from being those most radically opposed to a practical and extensive study of silicosis in Belgium.

The economic state of the country together with its industrial requirements are at present such that the greatest care must be taken to prevent manual labour from quitting certain industries in which, up till quite recent times, labour has been rather scarce. In principle employers are in favour of research effected in relation to the health of their workers. Many of them even encourage such research, yet all of them are insistent on the necessity of progressing with discretion and preferably limiting action to profiting by circumstances when workers spontaneously present themselves for medical examination, complaining of symptoms connected with the respiratory system. It is evident that in such conditions there is a risk that lack of positive data in sufficient number may yet delay the solution of the problem in Belgium for a long time.

It is good to be able to add, with a view to qualifying the lack of encouragement in the preceding paragraphs, that a new fact has just occurred which is capable of modifying considerably the situation. The Government has just granted a considerable subsidy (100,000,000 francs) for the anti-tuberculosis campaign.

Silicosis being often complicated with this disease to such a point that the two are associated under the names silico-tuberculosis and tuberculo-silicosis, it will probably be possible to organise a fairly extensive enquiry relative to silicosis properly so called. So far unofficial contact has been established with the medical authorities on whom shall rest the responsibility of organising this great campaign, which is in course of preparation. The above facts, however, only constitute matter for hope. In the meantime, a few facts are given below which show that here and there isolated research workers are engaged in praiseworthy efforts with a view to contributing by their personal research to a solution of the problem.

Dr. Courtois, attached to the Marcinelle Sanatorium, an institution founded fairly recently, presented to the last sitting of the Society of Scientific Studies on Tuberculosis an excellent work on the relation between tuberculosis and anthracosis occurring amongst sanatorium patients drawn from the mining population. The discussion of the question thus instituted will eventually be carried further.

Dr. Denet-Kravitz, Director of the Medical Social Dispensary of the Henricot Factories at Court-St. Etienne (Metallurgy), has interested himself particularly in the question.

In a note which he has sent me he states:

The first victims of silicosis which I had a chance of observing before the war or immediately after the armistice were authentic tubercular subjects dying more of tuberculosis than of pneumonoconiosis properly so called.

I have since then (in 1920) systematically examined all the workers who, amongst those submitted to me for examination, seemed to me likely to develop silicosis, the examinations in question being therefore preventive examinations of " non-sick workers ".

My first observations, published in January 1924, in the *Belgian Tuberculosis Review*, led to the following conclusions:

(1) Radiography is the only means of following the disease in its initial stages, clinical examination and radioscopy being insufficient.

(2) At the outset of the disease there is seen to develop a bundle of shadows, the accentuation of normal vascular and bronchial shadows starting from the hilum and spreading fanwise, then subsequently, contemporaneously with the lengthening of these shadows, a reticulated area which becomes closer and closer.

(3) Most frequently the apices are clear.

(4) The affection is not necessarily bi-lateral.

(5) Aggravation of the process is not in proportion to the length of exposure to the dust, the individual factor here playing a role of great importance (lymphatism).

I should like to draw attention to the fact that the results of my examinations are in accordance with the already old histological results obtained by Arnold, which showed the anatomopathological modification of the lymphatics.

In consequence of other observations published in the *Belgian Tuberculosis Review*, March-April-May 1926, I was led to conclude a scleroginous fibrofying action of the silica.

In the March-April 1928 number of the same *Review*, I described a case of nodular pulmonary sclerosis, interesting by reason of the fact that I had had the man in question under observation since 1921, at which time he still presented a negative radiological image and that having radiographed him periodically I had seen develop little by little an image comparable, one might say, to that of the corymbiform granular form of pneumonoconiosis starting from the hilar regions, and that though the patient had been for a long time withdrawn from the action of the vulnerating agent the process had continued (see Böhme). The B.C.G.

reaction (Calmette-Guerin test) had always been negative as well as the test for the bacillus in the sputum.

In No. 6, March 1928, of the *Review of Industrial Accidents*, I resumed my former observations, drawing a striking comparison between them and the works of Drs. Leon Bernard, Potter and Thomas on pulmonary sclerosis with arrested development, containing radiology identical with that which I had found for the sclerotic subjects at the outset—identical to such an extent that I was forced to ask myself if different causes might not be capable of setting up phenomena of the same character in specially predisposed subjects.

In the early cases which I have been able to observe there could have been no question of tuberculosis. In the pseudo-granular case (*le cas de pseudogranulie*) perhaps there is association, even though there ought to be taken into account the fact that this case has been developing for nine years back.

Finally, Dr. Stassen, Director of the Provincial Institution at Liége for the Study of Occupational Diseases, sends me the following communication:

Pneumonoconioses other than pulmonary anthracosis have also been made the subject of certain researches in the Province of Liége. On the initiative of the Permanent Deputation an enquiry was made in 1924 in the district of the Ourthe and Amblève quarries with a view to discovering whether diseases of the respiratory passages were particularly frequent amongst the quarrymen.

All the quarrymen suffering from pulmonary affections who believed in any direct or slight connection between such affection and defective working conditions were invited by posters to present themselves at certain hours fixed in advance for examination by the medical investigators. The latter in the course of their visit at the same time established contact with the medical practitioners in the neighbourhood of the quarries.

The enquiry lasted for six weeks, one sitting being held each week: 20 workers suffering from affections of the respiratory passages offered themselves for examination; 5 cases were retained as possibly being due to silicosis.

Two cases were radiographed, but the radiographic plates as well as the radioscopic images did not permit in any case of the detection of the characteristic signs of silicosis. The plates assembled did not differ remarkably from the radiographic plates of lungs infected by tuberculosis.

Amongst the tunnellers and perforating-machine men employed in excavating roads through stone strata in the coal mines we have found about 10 cases which might be suspected of being silicosis. As in the case of the quarrymen, however, the radiographic plates were not characteristic and might be confused with plates of other affections having no relation to the working conditions of the men in question.

SILICOSIS IN CANADA

BY J. G. CUNNINGHAM, M.B., DIRECTOR, DIVISION OF INDUSTRIAL HYGIENE, DEPARTMENT OF HEALTH, ONTARIO

From east to west in Canada, there is a widely diversified mineral production. Some of these operations are on a large scale. Gold is mined in nearly every Province. Nickel is limited to Ontario and asbestos to Quebec. Copper is important in British Columbia, Ontario and Quebec.

In manufactured products, Canada is second among the countries in the British Empire, and in terms of their gross value 80 per cent. of this industrial activity is centred in Ontario and Quebec. It is natural that industrial hygiene activities should have developed first in these two Provinces. Ontario established a Division of Industrial Hygiene in the Department of Health in 1920, and in Quebec such a Division was established in the Public Health Department of McGill University in 1928.

" Miners' phthisis " was included in the list of compensatable diseases enumerated in the Workmen's Compensation Act of Ontario in 1917. Its legal interpretation requires the presence of silicosis with active tuberculosis in a miner. The first case was compensated in 1924 on medical evidence submitted by Dr. C. D. Parfitt.

In the Alberta Workmen's Compensation Act, the disease in 1928 was designated: " Pneumonoconiosis which shall be deemed silicosis, siderosis, lithosis in quarrying, cutting, crushing, grinding or polishing of stone, or grinding or polishing of metal. Mining. " No cases have been compensated.

The Nova Scotia and British Columbia Workmen's Compensation Acts, while they do not specify silicosis as a compensatable disease, enable the workman to claim compensation for disease due to occupation as though it were a compensatable injury.

In Saskatchewan, the Workmen's Compensation Act, not yet in operation, provides for compensation of industrial workers suffering from silicosis, and for making regulations for the prevention of this and similar industrial diseases when necessary.

In Manitoba, in 1929, a Bill was introduced to the Legislature providing for the compensation and prevention of silicosis. This was set aside pending the recommendations of a General Committee now considering the existing Workmen's Compensation Act. In the meantime, the Mines Department has drafted rules, not yet in effect, intended to control the hazards from dust and tuberculosis in mines. Recently, the Provincial Department of Health has established a clinic for the examination of gold miners to determine whether silicosis is present.

In Ontario, silicosis has been the subject of clinical enquiry, particularly in the mining industry, in quarrying and among granite cutters. The pathology of the disease has been studied. The results follow.

Attention was first directed to the subject in 1924 in an article, "Silicosis in Ontario Gold Mines", by Dr. J. H. Elliott, who reported physical examination findings in eleven men who had been engaged in underground work in the Porcupine mines in Ontario for more than seven years with no other exposure to silica dust. Three of these men presented evidence of silicosis, indicating that the disease was being produced in this mining area. The recommendation was made and carried out that these men be placed at work on the surface away from exposure to dust. Up to the present time, two of them have progressed to the primary stage of silicosis and the other one has died with ante-primary silicosis complicated with tuberculosis.

Survey of Groups of Miners

In 1925 and 1926, a further survey was made by the Industrial Hygiene Division of the Ontario Department of Health, covering the four principal mining areas, all situated in the Northern part of the Province, viz. Porcupine, Kirkland Lake, Cobalt and Sudbury.

Miners with more than five years' experience underground in the individual mining area and with no exposure to silica dust elsewhere were to present themselves for physical examination. Some were included who had worked underground elsewhere.

The examination findings based on consideration of both physical condition and X-ray manifestations are reported in terms of the classification of stages of silicosis, developed by the South African Miners' Phthisis Medical Bureau. The interpretation of these standards was made possible through the guidance of Dr. J. M. Smith, of the South African Miners' Phthisis Medical Appeal Board, at the time of his visit to Ontario in 1927.

It is unnecessary to outline the details of the clinical classification or the pathological findings upon which it is based. These have been described in detail by W. Watkins-Pitchford in the *Journal of Industrial Hygiene* for April 1927, and by L. G. Irvine and A. Mavrogordato in the 1929 Report of the Convention of the International Commission for the Study of Occupational Diseases.

The years of exposure are based on statements made by the man at the time of examination. The occupational history was detailed from the time the man left school. Where, in view of age, it was apparent that this was incomplete, the history was carefully reviewed.

TABLE I. — SURVEY EXAMINATION FINDINGS, 1925 AND 1926

Mining area	Number of examinations	Stage of silicosis	Number of cases	Average years of exposure		
				Same area	Elsewhere in Ontario	Outside Ontario
Porcupine	236	Ante-primary	29	9	1	1
		Primary	9	9	0	0
		Secondary	8	10	3	4
Kirkland Lake	280	Ante-primary	11	3	5	5
		Primary	2	(Both outside Kirkland Lake)		
		Secondary	2	(Both outside Ontario)		
Cobalt	398	Ante-primary	6	11	2	6
		Secondary	1	12	0	0
Sudbury	306	Ante-primary	6	7	2	2

With one exception, the secondary cases were cases of silicosis with tuberculosis. This survey was the first chest examination conducted in these areas to include large numbers of miners. The findings, therefore, represent an accumulation of cases.

Extensive chemical and petrographical examination of mine rock samples to determine their free silica content, or dust counts to determine the number or proportion of silica particles under ten microns in mine air, have not been made.

The type of rock encountered varies considerably from area to area, from mine to mine in the same area and even from level to level in the same mine, so that the degree of exposure even for one occupation can be only approximate.

From the examination of such analyses as have been made, enquiry at the Ontario Department of Mines and the Dominion Geological Survey suggests that estimates may be made of the average free silica content likely to be encountered as appear in table II.

TABLE II. — CASES OF SILICOSIS WITH EXPOSURE IN ONE MINING AREA ONLY

Mining Area	Years of operation of area up to 1926	Probable percentage SiO_2	Number cases ante-primary	Average exposure in years	Number cases primary	Average exposure in years	Number cases secondary	Average exposure in years
Porcupine	14	25-35	17	9.5	9	9.5	3	10.6
Kirkland Lake	8	25-35	0	—	0	—	1	5 (crushers)
Cobalt	22	5-10	1	9	0	—	1	12
Sudbury	31	5-10	1	8	0	—	0	—

A few dust counts recorded in the article referred to above, " Silicosis in Ontario Gold Mines ", made with the Palmer Spray apparatus [1] and not distinguishing free silica from other dust present, showed the highest count under wet conditions as 17,400,000 particles under 12 microns in size per cubic foot of air. This cannot give more than a mere suggestion as to the exposure involved.

The average number of years of exposure of cases of silicosis among the men whose employment in mines was limited to the area in which they were examined during this survey follows.

Reference to tables I and II shows that, of the cases in the Porcupine area, over one-half had developed in that area. The average duration of exposure of these cases was low at 9.5 to 10.6 years.

[1] Comparative efficiencies of the Palmer Spray Machine, Sugar Tube and Greenburg and Smith Impinger are given as 1 to 2.1 to 5. (*Comparative Tests of Instruments for Determining Atmospheric Dusts*; Public Health Bulletin No. 144, United States Public Health Service.)

The rock conditions are such that exposure is high in free silica at times and very low at other times. Wet conditions have partly obtained since the early days of this mining area.

The Kirkland Lake area has not been in operation for a sufficient length of time to give any indication as to how much silicosis the area may produce.

It is interesting to note that in Sudbury and Cobalt, with a very low exposure to silica dust, among 300 and 400 men examined respectively, many of whom had worked underground in one or the other of these areas for twenty years and more, there appeared only three cases of silicosis advanced as far as the ante-primary stage. These men had worked underground for eight, nine and twelve years.

However, apparently in a few individuals even the low concentration of free silica encountered in this area can produce the disease.

A later case of secondary silicosis from the Cobalt area was a case of advanced silicosis with tuberculosis, with exposure in this area underground for twelve years and in the mill for five years. The lungs presented pigmented, visible, palpable nodules, widely distributed, a few of them, particularly under the pleura, at the right apex, large enough to conform to the outline of lobules. There was comparatively little pleural thickening, but extensive cavitation at the left apex and consolidation of the remainder of the left lung.

It should be recorded that in the Cobalt area, where the ore itself contains from 30 to 35 per cent. arsenic, in 398 examinations with stereoscopic X-rays of underground miners, most of them with over twenty years' exposure, there was no case of lung cancer.

In 1926, there was added to the list of compensatable diseases in the Workmen's Compensation Act, "Silicosis occurring in mines". Three stages of silicosis, ante-primary, primary and secondary are defined as in the South African Miners' Phthisis Act. To receive compensation for silicosis, the miner who has developed the disease must have been exposed to silica dust in his employment in Ontario for periods amounting in all to five years preceding disablement. The Act did not apply to those who had left their employment previous to April 1926, but these cases might be compensated as "miners' phthisis" cases if silicosis and tuberculosis with positive sputum was present. In such cases, the requirement for exposure is shorter.

In April 1928, an amendment to the Mining Act provides for physical examination on employment and yearly thereafter of each workman employed underground in all mines except those exempt by the Chief Inspector of Mines. At the same time, a " Certificate of Freedom from Pulmonary Tuberculosis ", in force for twelve months from the date of issue, is to be given to the workman, certifying that he is free from tuberculosis of the respiratory organs. This certificate is to be retained by the manager or superintendent at his request, during the period of employment, and returned to the workman on its termination or at the time of periodic examination. In the same year, an amendment to the Workmen's Compensation Act provided for the appointment of medical officers to carry out the physical examinations required under the Mining Act and defined tuberculosis of the respiratory organs as present, when on examination it is found that, (*a*) " such person expectorates the tubercle bacillus ", or (*b*) " such person has closed tuberculosis to such a degree as to seriously impair his working capacity and to render prohibition of work underground advisable in the interests of his health ".

By this time, the mine operators, of their own initiative, in the Porcupine and Sudbury areas, had already provided for physical examination with X-rays, of underground miners employed, and of applicants for employment. This procedure has been extended to all four mining areas. Examinations are conducted under the supervision of the Workmen's Compensation Board by physicians employed by it and paid out of assessments levied on mine operators for silicosis compensation purposes. Miners appear for examination in accordance with a pre-arranged schedule. Those meeting the requirements at initial or periodic physical examination are given a certificate in accordance with the Act. For identification, a photograph of the man with his X-ray number is taken at the same time and attached to the certificate. Cases of silicosis or silicosis with tuberculosis discovered in the course of these examinations are submitted by the examiners to the Workmen's Compensation Board. The claims include history of employment, medical history, record of physical examination findings with stereoscopic X-ray films of the chest.

When the history of exposure to silica dust in employment in Ontario mines for at least five years has been verified, the claims are passed for review to a Silicosis Referee Board composed of three members of the Ontario Department of Health. As a rule, the claimant is given physical examination by any two members of the Referee Board, which makes periodic visits to the camps for this purpose. The cases are then considered by all three members and a unanimous decision regarding the diagnosis is transmitted to the Workmen's Compensation Board.

As in the case of claims for accidents and other occupational diseases under the Workmen's Compensation Act, there is no appeal from the decision of the Workmen's Compensation Board except through the Board itself. Any claim may be re-opened for the Board's further consideration by the workman or employer, at any time, if new evidence is available.

Miners with a compensatable stage of silicosis are notified by the Workmen's Compensation Board that their claims have been allowed. At the same time, they are informed that if they continue in work exposing them to silica dust, and should the disease progress, they will be entitled to no further benefits. Should the miner cease work in which he is exposed to silica dust, and should the disease progress, he is then entitled to further compensation depending on the stage to which he ultimately progresses. When tuberculosis is present, the miner does not receive a certificate and cannot be employed.

The Silicosis Referee Board indicates when, in its opinion, the compensated cases should be re-examined for any purpose.

Findings in First Examinations of All Employed Miners

Hague and McBain reported, in an article entitled, " Silicosis as an Industrial Hazard in Ontario Gold Mining ", in approximately 3,000 examinations of miners employed underground in the Porcupine area, 39 ante-primary, 28 primary and 27 secondary cases of silicosis.

In Kirkland Lake in 1929, in 1,793 first examinations, there were 6 ante-primary, 6 primary and 4 secondary cases of silicosis. Their exposure averaged seven years in Ontario and four years elsewhere.

In Cobalt in 1929, in 662 first examinations, there were 7 ante-primary, 2 primary cases and one secondary case, with an exposure averaging thirteen years in Ontario and three years elsewhere.

In Sudbury in 1927 and 1928, among 1,434 first examinations, there were 6 ante-primary cases with an average exposure of twelve years in Ontario and none elsewhere.

Compensated Cases of Silicosis among Miners

Compensated cases are reported as from the mining area in which the claimant was last employed. Movement from one area to another is not infrequent. All cases in which the diagnosis has been established, have not necessarily been compensated, because of failure to satisfy other requirements of the Act. From April 1926 to 1 January 1930, there have been compensated 91 ante-primary, 58 primary and 33 secondary cases of silicosis. The proportion of secondary to total cases is high.

Up to 1 January 1930, of the compensated cases, one ante-primary case compensated in 1927 has progressed to primary and one ante-primary case compensated in 1928 has progressed to secondary. Three primary cases compensated in 1926, two primary cases compensated in 1927 and one primary case compensated in 1928 have progressed to secondary.

In the Porcupine area, of 27 secondary cases compensated to 1 January 1930, 15 have died. Of 17 secondary cases compensated in 1926, 9 died in 1926. Since then 10 more secondary cases have been compensated and 6 have died. In the 15 death cases, the period which elapsed between the time they were compensated, which in most cases was shortly after disability arose, and the date of death, averaged sixteen months. The compensated secondary cases still living at 1 January 1930 have averaged twenty-seven months since compensation was awarded.

Some interest attaches to the group of cases among the claims for compensation submitted from the Porcupine area, which have been examined by the Silicosis Referee Board.

TABLE III. — CASES FROM PORCUPINE AREA EXAMINED BY SILICOSIS REFEREE BOARD, 1927-1930

Distribution of all cases		Distribution of 35 secondary cases	
Stage of silicosis	Number of cases	Stage of silicosis	Number of cases
		Uncomplicated secondary	4
Ante-primary	20	Ante-primary and tuberculosis	7
Primary	9	Primary and tuberculosis	6
Secondary	35	Secondary and tuberculosis	9
		Silicosis and tuberculosis	9

In this group, just under one-half of the cases are complicated with tuberculosis. Nine cases reached the secondary stage before the development of tuberculosis, but in most of them signs of active tuberculosis followed rapidly.

Among the secondary cases are two which developed tuberculosis some years after leaving the mines for work in the forest. One had worked underground in the Porcupine area for six years up to 1920 and one had worked in the Porcupine area for seven years up to 1919, that is, the development of tuberculosis was nine years and ten years after removal from exposure. These cases did not meet the requirements of the Act and were not compensated.

The "silicosis and tuberculosis" cases were mainly cases which came to attention early in the work when tuberculosis already masked the late evidences of advancing silicosis that may have been present. In a few cases, the silicosis was of the massive bilateral type with signs and symptoms indicative of superimposed tuberculous activity.

The tubercle bacillus has not been demonstrated in the sputum of silicotics with tuberculosis as early, or as readily as might be expected. This holds for both examination of smears, using concentration methods and also for animal inoculation. Animal inoculation has frequently produced a typical lesion, months before the detection of the organism by repeated examinations of smears. In seven secondary compensated cases positive sputum was detected on an average nine months before death.

It is impossible to indicate what yearly incidence of silicosis among miners in these areas may be expected. The arrangements for examinations have not been completed for a sufficient length of time to warrant conclusions.

Applicants for Employment

The number of rejections on physical examination with X-rays, varies from area to area, from 5 to 10 per cent. of those sent from the mine employment office. This percentage is very low compared with South African experience, but may be influenced by the form of certificate, which certifies only " to freedom from tuberculosis " without reference to fitness for underground work, although in the examinations this may be taken into account.

In one area, where the numbers employed have largely increased recently, among 4,700 examinations of applicants in two and a half years, there were 22 cases of ante-primary silicosis and one case of secondary silicosis, all from outside Ontario. In this respect, examinations have acted as a protection against claims on mines operating in Ontario, for which they are not responsible.

Simple Tuberculosis

The Survey of 1925 and 1926 involved single physical examinations with stereoscopic X-ray films, so that there was no opportunity to determine definitely the presence of tuberculosis in suspected cases. Most of the men examined had been employed in mines in Ontario for over five years.

TABLE IV. — INCIDENCE OF "SIMPLE TUBERCULOSIS" ON SURVEY OF GROUPS OF MINERS IN 1925 AND 1926

Mining area	Number of examinations	Cases of tuberculosis
Porcupine	236	10
Kirkland Lake	280	8
Cobalt	398	10
Sudbury	306	5

Reference to the report by Hague and McBain on the findings in the first year's examinations at Porcupine shows under tuberculosis that the first two groups designated those "showing positive sputum" and those "showing a definite risk" taken together, and the last two groups, those "with slight risk" and those with "apparently non-significant peribronchial tuberculosis" taken together present a relative incidence among employees and among applicants expressed as 2 : 1. The group of employees "showing positive sputum" and "showing definite risk", were 2.6 per cent. of those already employed.

In this area, in 1929, after two periodic examinations among 2,330 employees, there were 6 cases of simple tuberculosis, similar to the yearly incidence among European miners in South African gold mines. Three of them were Finlanders.

In Kirkland Lake, in 1929, among 1,800 first examinations of employees, there were 12 cases of simple tuberculosis.

In Cobalt, in 1929, among 662 first examinations of employees, there were 5 cases of simple tuberculosis.

In Sudbury among 1,434 first examinations of employees in 1927 and 1928, there were 23 cases of simple tuberculosis. In 1929, among 1,958 examinations of employees there were 4 cases of tuberculosis. In this area among 4,700 applicants, there were 149 cases of tuberculosis, and suspected tuberculosis.

Tuberculosis is not compensatable. There can be little doubt that as the importance of dust and tuberculosis in the mines has been more generally recognised, a number of men with tuberculosis or suspected tuberculosis have discontinued underground mining before the initial examinations were completed.

In an investigation by the Commonwealth Department of Health, among 4,067 gold miners in Western Australia (Kalgoorlie), there were 0.3 per cent. with simple tuberculosis.

The Report of the Technical Commission of Enquiry to investigate " the prevalence of miners' phthisis and pneumonoconiosis in the metalliferous mines at Broken Hill " showed 1 per cent. of underground miners with simple tuberculosis.

In New South Wales, of 716 men examined, not all miners but with some exposure to silica dust, there were 16 cases of simple tuberculosis (2.2 per cent.).

In Bulletin No. 162, the United States Public Health Service reports the tuberculosis rate for all ages among 10,000 male industrial workers as 2.5 per cent. and among foundry workers as 1.9 per cent.

TABLE V. — COMPARISON OF MORTALITY STATISTICS OF " UNDERGROUND MINERS AND ALL MALES OVER 15 YEARS ", 1925 TO 1929, BY AREA

Mining area	All males, deaths, pulmonary tuberculosis	Estimated proportion miners to adult male population	Miners' deaths, pulmonary tuberculosis	Miners' deaths, all causes	Miners' deaths, pneumonia	All males, deaths, pneumonia
		Per cent.				
Porcupine	22	60	13	94 + 33[1]	24	54
Kirkland Lake	6	45	5	33	2	3
Cobalt	5	25	4	54	5	12
Sudbury	18	55	3	46	7	54

[1] One accident.

The figures are small. Sanatorium deaths from tuberculosis are allotted to the area from which admission to the Sanatorium was made. The proportion of the population in the lower age group is probably higher in these areas than in most communities. No important increased proportionate mortality is shown to exist for tuberculosis. It is high for pneumonia in Porcupine.

The available information suggests that there are no important variations in the number of cases of simple tuberculosis from one area to another and that there is no marked increase in these miners over those employed in mines elsewhere or in other heavy trades.

Tuberculosis in Children of Miners

In the course of one of the clinics conducted by Dr. G. C. Brink, of the Tuberculosis Section of the Preventable Diseases Division of the Department of Health, there were examined 73 children in the centre of the Porcupine area. Forty-six of these were the children of miners. There was among them one child with positive tuberculosis and 19 showing a positive tuberculin reaction. These children were between the ages of one and fourteen. Among 27 children whose fathers were not miners, there were 8 showing a positive tuberculin reaction.

Cost of Silicosis in Miners

An ante-primary case is awarded $500, a primary case $1,000, and a secondary case, total disability. For total disability, the workman receives $66^2/_3$ per cent. of his previous wages, medical and hospital care. In the event of death, a pension is paid in accordance with the number of dependants.

Ninety-one ante-primary, 58 primary and 33 secondary cases of silicosis, of which 18 have died, have cost $268,356. Of this amount $111,196 was for the death claims. In addition, there has been set aside $282,500 for continuing claims and $69,000 for claims reported but not adjusted.

Control of Dust

The Mining Act of the Province of Ontario requires the control of dust underground.

Every dusty place where work is carried on in a mine must be adequately supplied with clean water under pressure. In a few mines, wet conditions prevail naturally, but in all mines, stopes, raises and drifts are kept wet. The use of wet drills since 1924 has been compulsory and water is used in collaring holes.

Attempts are made to limit dust generated in handling ore by the suitable location and design of ore passes. On account of climatic conditions, hoisting shafts are necessarily upcast shafts, thus the dust created at ore passes is carried up and out of the mine, instead of being distributed through it. Canvas screens continuously supplied with water have been used in front of ore pass openings.

The Mining Act provides that the times for blasting shall be so fixed that the workman shall be exposed as little as possible to dust and fumes. As a rule, blasting is done at the end of the second shift so that the mine is idle until the first shift of the next day comes on duty. After blasting, a small amount of water is turned into the air lines which are operated to blow out the fumes, thus a mist is created which assists in carrying down dust. This is looked upon as one of the most important measures that have been adopted from the standpoint of both fumes and dust.

In some cases, blasters are using masks of the filter type. Dust counts made of samples of air from within these masks have shown an important reduction in the count.

The rock temperature with the depth reached has not risen above 67° F., so that heat is not a problem in these mines. Relative humidity is about 95 per cent. In winter, the difference in temperature at the surface and underground favours natural ventilation. In some of the mines, huge fans have been installed in shafts, delivering from 150,000 to 250,000 cubic feet of air per minute giving a linear velocity up to 8 miles an hour in drifts. These fans, on account of climatic conditions cannot be operated during the winter except where the air is led into the mine through old workings not in use. Auxiliary fans delivering fresh air through canvas or metal tubing to development faces are widely used. In one instance, a special shaft has been built for forced ventilation and in another, a special compartment in a shaft has been set aside to assist natural ventilation in the removal of fumes and dust.

Granite Cutters

In Ontario in 1924, there were examined 110 men quarrying and crushing rock for use in the manufacture of ferro-silicon. The free silica content is high. The exposure in most cases was limited to a few years for the summer months only.

There were 5 ante-primary and 3 secondary cases of silicosis, all but one having had exposure elsewhere. The single case referred to had exposure at the crusher for four years of six months each, and none elsewhere. At the time of examination, three months before his death, there was dyspnoea, marked on exertion, poor expansion with indrawing of the intercostal spaces and evidence of consolidation in the upper portion of both lungs. The X-ray presented massive consolidation to the fourth rib anteriorly on each side with less dense shadows and mottling in the fourth and fifth interspaces. Pathological examination revealed a massive fibrosis of silicotic type in the upper two-thirds of both lungs. The case has been fully reported by Dr. A. R. Riddell in an article entitled " A Case of Silicosis with Autopsy ". Further examination of this case, showed the presence of small tubercles in the spleen, and the cell reaction suggests that the lung was involved.

At this time, 1924, silicosis was compensatable only as " miners' phthisis in mines ". Locally, such a situation left operating companies open to civil suit for silicosis contracted in other industries.

In 1925, in Ontario, provision was made for the compensation of cases of stone workers' or grinders' phthisis in quarrying, cutting, crushing, grinding and polishing of stone or grinding or polishing of metal. In 1926, pneumonoconiosis was added to the list of compensatable diseases to apply to the same industries as stone workers' or grinders' phthisis. The difference lies in interpretation of the Act. The presence of silicosis with active tuberculosis and positive sputum is required under grinders' phthisis.

Exposure of granite cutters in this Province is mainly from the dust from Barre light granite, Quebec Stanstead granite, Georgia granite and Balmoral red granite. The first three contain about 35 per cent. free silica. Many of these granite cutters have cut sandstone or been exposed to dust from the sandblast.

A few dust counts, made with the Palmer Spray apparatus, have shown big variations at the breathing level of workers using different kinds of tools. With the use of the heavy picker for surfacing, counts ran from 106,000,000 to 220,000,000 particles of dust (not SiO_2 alone) under 10 microns in size, per cubic foot of air. The shop air away from these tools was usually under 5,000,000 particles per cubic foot. No detailed study of dust content of air was made.

In 1928 and 1929, the Industrial Hygiene Division conducted examinations of 133 granite cutters with over fifteen years' experience in the trade, with the results shown in table VI.

There are roughly 500 granite cutters in the trade in the Province, so that the accumulation of cases is not high. Attention is rather arrested by the number of granite cutters who have worked twenty years or more at the trade without presenting more than an increase in fibrosis of the lungs, producing no symptoms. The proportion of complicated cases to total cases is high compared with that found in the survey of miners.

TABLE VI

Stage of silicosis	Number of cases	Average years of exposure	
		In Ontario	Elsewhere
Ante-primary	19	20.6	11.1
Primary	5	27.6	4.5
Secondary	10	19.3	13.1

It is interesting to note that these cases present findings on physical examination with X-rays, which make it possible to divide them in accordance with the classification of ante-primary, primary and secondary. The secondary cases reported, with one exception, were cases of silicosis and tuberculosis. Only a few of them presented massive consolidation similar to that described as occurring among Barre, Vermont, granite cutters. While some of the secondary cases have died, none have come to autopsy.

The shops are, as a rule, small, frequently with only one or two cutters, so that most of them do all types of work. Many of these shops have indifferent exhaust equipment for the removal of dust, especially from surfacing machines. The work is done under dry conditions and the floors are covered with rock dust.

In March 1929, the Silicosis Act for the " better prevention of silicosis among stone workers " was passed in Ontario. This Act requires examination on employment and periodic examination of granite cutters. The details for these examinations have not yet been arranged. The Factory Inspection Branch of the Department of Labour will supervise appliances used for the control of dust when this Act comes into force.

A positive pressure mask, devised by Dr. F. M. R. Bulmer, of the Division of Industrial Hygiene, is in fairly widespread use among granite cutters. It is easily adjusted, comfortable and inexpensive. Suitable cloth is held over the face by rubber bands which tie behind the head. It is ballooned with filtered air, from a compressor, which escapes from the sides and front of the mask to keep it cool and to prevent inspiration of dust or fumes. It is not intended as a substitute for the mechanical control of dust.

TABLE VII. — A FEW ADDITIONAL CASES REFERRED TO THE DIVISION FOR EXAMINATION

Occupation	Stage of silicosis	Number of cases	Average years' exposure
Sandblaster	Secondary	1	15
Moulders	Primary	1	40
	Primary	1	23
	Secondary	1	12
Grinders	Ante-primary	1	2½ (sandstone) 8½ (artificial)
	Primary	1	8 (sandstone) 5 (artificial grindstone)
	Primary	1	40 (sandstone)
	Secondary	1	12 (sandstone)

These were all cases with nodular fibrosis, and considered with other cases reported, having various types of exposure to silica, suggest that the inhalation of dust, for a period, containing free silica alone, may determine the widespread distribution of fibrosis.

In the course of investigation of hazards to health in other industries, the following physical examinations with X-rays, of interest in reference to silicosis, have been conducted.

TABLE VIII. — EXAMINATION OF WORKMEN EXPOSED TO DUSTS OTHER THAN SILICA

Industry	Number of men examined	Average years' exposed	Approximate SiO_2	Physical findings
			Per cent.	
Cement workers	26	19	1	No silicosis
Brick and tile workers	34	19.3	1-10	No silicosis
Grain elevator workers	68	16.7	3	No silicosis
Artificial abrasive, manufacture and use (silicon carbide and aluminium oxide)	68	7.9 [1]	0.3	No silicosis

[1] Twenty-seven of these 68 men had an average exposure of thirteen years.

Physical Examination Findings

In Ontario miners the symptoms present in the ante-primary stage of silicosis have been an irritating cough, frequently in the morning, with shortness of breath on moderate exertion, rather more than is expected. On examination there have been no characteristic signs. Frequently, there is diminished expansion, sometimes very marked, with slightly diminished resonance in the upper two-thirds of the chest and breath sounds diminished and sometimes slightly higher-pitched, no appreciable change in voice transmission. As the condition progresses, these symptoms and signs are emphasised, that is, diminished resonance, high-pitched breath sounds with apparent shortening of the inspiratory phase compared with expiration. Rales are seldom heard unless tuberculosis complicates the condition. The X-ray presents increased hili shadows and linear markings with diffuse mottling, frequently more marked in the inner and middle zones on the right side.

The advent of tuberculosis has manifested itself by an aggravation of existing symptoms and others common to tuberculosis, and in the X-ray by a less discrete outline to the nodular shadows with local conglomeration, usually in the upper third of one or both lungs.

Among the granite cutters, after a much longer exposure to dust containing free silica, the manifestations of the disease were much the same as in miners, contrary to the experience of Jarvis [1] and later, Russell [2] with Barre, Vermont, granite cutters. Rather than a massive local fibrosis suggesting itself by the physical signs, decreased expansion, diminished resonance, high-pitched breath sounds and diminished voice transmission limited to one area bilaterally, with corresponding conglomerate shadows in the X-ray and the remainder of the lung fields fairly clear, the distribution of fibrosis in the Ontario cases, as a rule, has been the same as that presented by the miners, although the linear markings often cast deeper shadows and discrete nodules are more common in the hili shadows, probably associated with longer continued exposure to dust. However, in a few cases, more frequently in granite cutters than in miners, localised conglomerate shadows extending from the hilum outward and upward appeared as the important X-ray manifestations of the disease. The other physical findings in such cases were localised.

When tuberculosis supervened even in these cases, it was usually apical and not basal, as in the Barre, Vermont, granite cutters.

[1] D. C. Jarvis: "A Conception of the Chest Röntgen-Ray Densities Based on a Study of Granite Dust Inhalation." *American Journal of Roentgenology*, April 1922, Vol. IX, No. 4, p. 266.

[2] A. E. Russell: *The Health of Workers in Dusty Trades*. [2. Exposure to Siliceous Dust (Granite Industry).] United States Public Health Bulletin No. 187.

Pathology

The pathological findings in some of these cases have been discussed by Riddell and Rothwell in " Some Clinical and Pathologic Observations on Silicosis in Ontario ".

Here observations were made corresponding to those described by South African workers as the basis for their classification of cases. Attention is drawn to atypical cases in which there was widespread invasion of lung tissue by fibrous tissue without palpable nodules but with " fibrous whorls " in microscopic section.

In these cases, there was moderate exposure to free silica and the ash of the lungs showed a comparatively high silica content.

The marked difference between the silica content of the ash of lungs in adults not especially exposed to silica dust and that among miners is indicated, with a description of the gravimetric method used for the chemical determinations. Since that time, E. J. King, reporting difficulty with the use of Isaacs' method for the estimation of silica in tissue, described a micro method for this purpose which depends on the production of yellow silicomolybdic acid, which gave accurate results.

Studying these with other lung specimens, T. H. Belt, at work in the Pathological Department of the University of Toronto, reported in " Silicosis, Its Pathology and Relation to Tuberculosis " the result of a comparison between the silica content of the ash of the lungs of silicotics and the number of particles of silica to be seen in adjoining portions of the same lung with the polarising microscope.

The invisible portion designated " occult silica " was greatest where fibrosis was most extensive, i.e. few particles to be seen, a high silica content on chemical examination, and extensive fibrosis, are related. This appears to support the theory of Gye and Kettle that crystalline silica produces its ill-effects on account of a slow chemical change, probably to colloidal form.

No silica particles were noted in the fibrotic nodules, but they appeared in the zones surrounding these nodules, which were occupied by young fibroblast and endothelial cells. With few or no silica fragments, the presence of a healed lesion suggested the absence of any irritant and the assumption that the silica by this time has changed to silica gel. With this conception of the sequence of events, fibrosis will continue for some time after exposure has ceased, until the silica already in the lung has been rendered innocuous. This is noted in explanation of the clinical progress which takes place in uncomplicated silicotic cases after removal from exposure to silica.

In the cases with tuberculosis, the fibrous nodules largely escaped caseous necrosis, but the zone surrounding them in which the silica particles lie was necrotic and without any evidence of cell reaction except at its edge. Extensive cell reaction occurred in the normal lung and away from the fibrotic areas. So that it is inferred that tuberculosis gains a foothold in the areas surrounding the fibrous nodules called " silica nests ", and that so long as these areas have not become fibrosed the increased liability to the spread of tuberculosis infection exists.

G. C. Cameron, associated with the Banting and Best Chair of Medical Research, has been good enough to abstract for this summary an unpublished paper describing " An Experimental Study of Elimination of Silica from the Lung ", 1 January 1930:

The work was based upon the observation personally conveyed by Professor Oskar Klotz that the lung alveoli of anthracotic subjects dead of pneumonia often contained many phagocytes which were heavily laden with carbon. We sought therefore an agent which upon introduction to the air spaces of the lungs would promote emigration of phagocytes and at the same time be innocuous to the subject. It was presumed that the emigrating phagocytes would carry with them their previously ingested content of silica.

It was found that rabbits might be enclosed in a chamber the atmosphere of which was heavily charged with paraffin oil in droplet form, as discharged from an atomiser. Prolonged exposure of several hours daily did not seemingly impair the health of the animals.

Histologic study of the lungs of such animals showed that exposure for an hour sufficed to disperse oil widely throughout the lungs, and that oil could be demonstrated in the lungs as long as fifteen weeks after the cessation of exposure. The oil promoted very active emigration of phagocytes to the alveoli, from where it was presumed they were expectorated with a full capacity of oil. Oil was observed in the parenchyma of the lungs in only one of the twenty-seven rabbits exposed. In this instance, the oil was evidently being conveyed along the lymph channels and was demonstrable in small amounts in lymph nodes. In none of the animals did the oil occasion fibrosis that might occlude air spaces.

Rabbits exposed to an atmosphere highly charged with finely particulate quartz dust both before and during the exposure to oil spray were killed, and the lungs examined histologically and chemically. The production of histologically demonstrable silicosis was not achieved during the period of observation and chemical estimation of silica in the lung by the colorimetric method of King[1] did not indicate that elimination of silica from the lung, in the sense of complete expectoration,

[1] E. J. King: " Estimation of Silica in Tissues. " *Journal of Biological Chemistry*, 1928, Nov. 1928, p. 25.

was accomplished. As the chemical procedure would not differentiate between silica in the tissue and silica in the air spaces, however, it was felt that this result did not indicate complete failure of the method.

The *process* of elimination of particulate foreign matter from lung parenchyma by administration of oil spray was demonstrated by experimentation with carbon. Rabbits were made anthracotic by intravenous administration of India ink and then subjected to oil spray. The air spaces of the lungs of these animals contained many cells which had ingested both carbon and oil, apparently to the limit of their capacity. Lungs of control animals untreated by oil showed absence of phagocytes in the air spaces but very many cells heavily laden with carbon in the parenchyma. The lungs of animals intensively treated with oil showed microscopically some months after cessation of treatment approximately as much carbon as the untreated controls, so that the practicability of oil spray as a therapeutic measure was not proven. Experiments are proceeding.

Summary

(1) The cases reported indicate that silicosis, as defined by the standards of the Miners' Phthisis Medical Bureau of South Africa, is contracted in gold mining in Ontario. The number of cases in proportion to the number employed underground is not high, but the time required for the development of these cases is relatively short. The proportion of silicosis cases complicated with tuberculosis is high.

(2) The number of cases and deaths from simple tuberculosis is little, if any, higher than that found in mines elsewhere.

(3) Granite cutters in Ontario develop silicosis with manifestations similar to those presented by Ontario miners. The proportion of cases found during the survey of those employed at the trade for more than fifteen years, is low, having in mind the skilled nature of the employment and the consequent high percentage with long service. The period of exposure to silica dust in all cases is long. The proportion of silicosis cases complicated with tuberculosis is high.

* * *

The writer wishes to acknowledge valuable assistance in the preparation of this summary from:

Mr. V. A. Sinclair, K.C., Chairman, and Mr. T. N. Dean, M.A., F.S.S., Statistician, Workmen's Compensation Board, Ontario.

Dr. N. H. Russell, Dr. E. A. Morgan and Dr. R. W. McBain, Examining Physicians in the mining areas.

Professor O. E. KLOTZ and Dr. T. H. BELT, who has examined and reported in detail for the Department on the pathological specimens submitted to the Department of Pathology, University of Toronto.

Dr. G. C. CAMERON, Banting and Best Chair of Medical Research, University of Toronto.

Dr. A. R. RIDDELL and Dr. G. C. BRINK, of the Silicosis Referee Board, Province of Ontario, and Mr. S. J. MANCHESTER, Director, Division of Vital Statistics, Department of Health of Ontario.

BIBLIOGRAPHY [1]

ELLIOTT, J. H. " Silicosis in Ontario Gold Mines ". *Canadian Medical Association Journal*, Oct. 1924.

HAGUE, O. G. and McBAIN, R. W. " Silicosis as an Industrial Hazard in Ontario Gold Mining ". *American Journal of Roentgenology and Radium Therapy*, Vol. XVIII, No. 4, Oct. 1927, p. 315.

RIDDELL, A. R. " A Case of Silicosis with Autopsy ". *Canadian Medical Association Journal*, 1925, Vol. XV, p. 839-841.

—— and ROTHWELL, H. E. " Some Clinical and Pathologic Observations on Silicosis in Ontario ". *Journal of Industrial Hygiene*, Vol. X, No. 5, May 1928, p. 147.

BELT, T. H. " The Pathology of Silicosis of the Lung ". *Canadian Public Health Journal*, Vol. XX, No. 10, Oct. 1929, p. 494.

KING, E. J. " The Estimation of Silica in Tissues ". *Journal of Biological Chemistry*, Vol. LXXX, No. 1, Nov. 1928. p. 25.

[1] This Bibliography is limited to Canadian references.

APPENDIX

THE MINING ACT

CERTIFICATE OF FREEDOM FROM PULMONARY TUBERCULOSIS

Serial Number ...... Date ....

Name ....

Address ....

Nationality...................................

Married .... Single .... Age......

Signature of Workman....................

Personal Photograph
Full Face View

Photograph to be also signed

The Workmen's Compensation Board
ONTARIO

This certifies that I have examined

....

whose photograph is attached hereto and have found him free from tuberculosis of the respiratory organs.

If required by the Manager or Superintendent, this certificate shall be delivered to him, and shall remain in his custody until the holder is discharged.

DATE OF INITIAL EXAMINATION

....

1. Date due for re-examination

....

Examined— Doctor's Signature

....

2. Date due for re-examination

....

Examined— Doctor's Signature

....

3. Date due for re-examination

....

Examined— Doctor's Signature

....

N. B. — The holder of this certificate must be re-examined not later than twelve months from date of initial examination, and annually thereafter.

SILICOSIS IN GERMANY

I. — PRESENT STATE OF THE SILICOSIS PROBLEM IN GERMANY

BY PROFESSOR A. BÖHME, BOCHUM

INTRODUCTION

The exposition of the present state of knowledge relative to the silicosis problem in Germany should be preceded by a short discussion of the principal features of its development in our country. Only a few names need be mentioned. The first German author to deal with injury to the lungs of miners caused by inhalation of dust, and to designate such injury as an occupational disease, was Paracelsus, who, about 1534, published his work entitled *Miners' Phthisis and Other Miners' Diseases.* In the second half of the nineteenth century, German pathologists and clinicians made considerable progress in regard to research connected with diseases caused by dust.

Zenker [1] provided the anatomical, and Kussmaul [2] the chemical, proof of the deposit of inhaled dust, especially silicic dust in the lungs. The name pneumonoconiosis was invented by Zenker, who described in detail the anatomical picture of the dusty lung. Merkel [3] studied the tubercular changes in siderotic lungs. The fundamental experimental and anatomical research engaged in by Arnold [4] constituted considerable progress. He succeeded in producing experimental dust fibrosis of the lung, and in distin-

[1] ZENKER, in *Deutsches Archiv für klin. Med.*, 1866, Vol. II.
[2] KUSSMAUL, *ibid.*, Vol. II.
[3] MERKEL, *ibid.*, 1887, Vol. XLII.
[4] ARNOLD: *Untersuchungen über Staubinhalation und Staubmetastase.* Leipzig, F. C. W. Vogel, 1885.

guishing clearly between that and tuberculosis. Eulenberg [1] definitely affirmed that silicic acid causes serious fibrotic disease of the lungs.

A close connection between the inhalation of dust with a quartz content and tuberculosis has been revealed repeatedly by statistical data: Oldendorff [2], Sommerfeld [3], Moritz and Röpke [4] and others draw attention to the high mortality rate from tuberculosis amongst metal grinders; Lewin (1863), Hirt [5], Wilbrandt [6], Eulenberg, Sommerfeld [7] and others to similar conditions amongst pottery workers.

For extensive hygienic research relative to the dust content of the atmosphere, to the deposit of dust, to the self-protecting mechanism of the system against injury due to the dust, we are indebted to Lehmann and his collaborators [8].

Clinical Picture of Silicosis

The clinical picture of the silicotic lung could only be studied in the case of very advanced disease forms prior to the introduction of Röntgen ray examination. Bäumler [9] describes the symptoms, and lays stress on the cirrhotic character of the accompanying tuberculosis.

The accurate diagnosis of silicosis during life, as well as in its early stages, and investigations relative to its incidence in the several occupations involving exposure to this risk, as well as a study of its development, were only rendered possible by the introduction of the Röntgen diagnosis. On the basis of earlier discoveries, Staub-Ötiker [10], the next writer to describe in detail the radiographic picture of the silicotic lung as found in metal-grinders, also distinguished the various stages of the disease. Numerous further radiographic and clinical studies have since been effected. Comprehensive expositions of the subject are provided

---

[1] Eulenberg: *Handb. d. Gewerbehyg.* Berlin, 1876.
[2] Oldendorff, in *Zentralbl. f. allgem. Gesundheitspfl.*, 1882.
[3] Sommerfeld, in Beil. z. *Hyg. Rundschau*, VII. Jahrg., No. 1, 1897.
[4] Moritz and Röpke, in *Zeitschr. f. Hyg. u. Infektionskrankh.*, Vol. XXXI.
[5] Hirt, in *Krankheiten der Arbeiter*, Vol. I. Breslau, 1871.
[6] Wilbrandt, in *Vierteljahrsschr. f. gerichtliche Mediz.*, Vol. XXIV.
[7] Sommerfeld, in *Deutsche Vierteljahrsschr. f. öffentliche Gesundheit*, 1893, Vol. XXV, No. 2; *Handb. d. Gewerbekrankheiten*, Berlin, 1898.
[8] Lehmann, in *Archiv f. Hygiene*, Vol. LXXV; also in *Arbeits- u. Gewerbehygiene*, Leipzig, 1919; Lehmann, Saito and Gefrörer, in *Archiv f. Hyg.*, Vol. LXXV.
[9] Bäumler, in *Münch. med. Wochenschr.*, 1909, No. 10.
[10] Staub-Ötiker, in *Deutsches Archiv f. klin. Med.*, 1916, Vol. CXIX.

by Stähelin [1], Ickert [2], Jötten and Arnoldi [3], Lehmann-Engel-Wenzel [4]. The lines followed by the above researches are somewhat as follows:

In very many dusty trades, as, for instance, among bakers and millers, who suffer from bronchitis, often amongst coal miners (hewers), and likewise in the initial stages of silicosis, there is found an enlargement and mottling of the hilar shadow, thickening of the trunk shadows proceeding from the hilus, intensifying of the outline of the lungs which reaches to the border of the chest and shows arborification, giving a picture resembling a network, with prominence of the bronchial tubes in the form of longish cavities with a double-edged border. From the anatomical point of view such a picture corresponds to a type of bronchitis—a filling-up of the peribronchial and perivascular lymph cavities with coal dust, without fibrosis; also eventually to an initial dust fibrosis of the lung.

Such a picture is found, for instance, frequently amongst rockdrillers in coal mines, where, associated with initial fibrosis, there is found considerable deposit of coal dust in the lung.

Among cement workers, polishers in the knife-grinding industry, and coal miners (hewers), this picture is very frequent. Symptoms are not as a rule associated with these slight modifications unless there is bronchitis. The pictures above described do not indicate silicosis.

Where definite fibrosis develops, the knots of the reticulated area are seen to thicken, the single outline of the lung resolves itself into small round spots which are partly ranged one behind another like beads in a necklace, or there may be seen, quite apart from the outline of the lung, various small spots within the lungs, at first more especially in the centre, but which gradually invade and cover the outline of the lung. This picture is characteristic of dust fibrosis, as met with more especially after inhalation of quartzitic dust, but possibly also after deposit of coal dust or graphite.

With the development of the disease, the fine mottling spreads over the lungs in an almost symmetrical manner, though the right side is somewhat earlier and more intensely involved than the left.

[1] STÄHELIN, in *Handb. d. norm. u. pathol. Physiologie*, Vol. II, p. 515. Berlin, 1925.

[2] ICKERT: *Staublunge u. Staublungentuberkulose*. Berlin, 1928.

[3] JÖTTEN and ARNOLDI: *Gewerbestaub- u. Lungentuberkulose*. Berlin, 1927.

[4] LEHMANN-ENGEL-WENZEL: "Der Staub in der Industrie", Beiheft z. *Zentralblatt f. Gewerbehyg. u. Unfallversicherung*, Vol. IX.

The apical zones are usually less affected than the other parts of the lung, but in the end they also generally become involved. According to the nature of the dust, the Röntgen slides reveal at this stage certain differences. According to Kaestle, the mottling shows deeper shadows and sharper edges the higher the quartz content of the dust. He has thus observed a specially intensive mottling in workers engaged in sandstone quarries; such pictures are also met with in the case of steel-grinders, who work with wet sandstone. The mottling becomes gradually more intensive and larger, but the spots seldom exceed a few millimetres in diameter. They may in places be so thick as to appear to overlap.

Regarded from the anatomical point of view, the small spots cluster round fibrotic foci, with a rich dust content which in their central zone are mostly transformed into hyaline. Signs of infection, especially of a tubercular nature, are not in general to be found in these small nodules. With the developing thickness of the fine mottling, the elasticity and vital capacity of the lung becomes reduced, and there arises a certain amount of dyspnoea on effort (*Arbeitsdyspnoe*). A dry cough is often met with; sounding reveals, however, bronchitic respiration only in a fraction of the cases—at least where stonecutters are concerned. The percussion note (*Klopfschall*) is as a rule hardly worth considering. Where the radiographic picture reveals special thickening of the fine nodules, the sound may in this region be somewhat shortened, as for instance, where the side, in the axillary region or the interscapulary region is heavily involved. In some forms of silicosis bronchitis appears to play a rather important part.

In the further development of the disease, there are recognised on the Röntgen plate, large, dense, circumscribed masses of shadow, often enclosed by sharp edges, which frequently develop symmetrically, but also at times asymmetrically. Favoured situations for these massed shadows are the sides of the infraclavicular regions on each side, and also those parts which project in a lateral direction from the hilus. These masses of shadows with large mottling may become greatly extended in the course of a few years and finally cover the greater part of the lung.

It is especially the middle and upper parts of the lung which generally become filled with these masses of hard cicatricial tissue showing a strong tendency to shrinkage, whilst in the lower parts of the lung there develops a marked secondary emphysema to which the indurated changes formerly present there gradually give place. Descending trunk shadows reaching from the large shadow masses down to the diaphragm, and intense displacement of the diaphragm complete the picture. Ultimately it not infrequently happens that an enlargement of the heart is established radiographically. With the increase in indurated phenomena there sets in also marked diminution in the percussion note (*Klopfschall*), modifications of the respiratory murmur, which may at times be softer and at times harsher. Rales are then usually rare. The capacity for chest expansion and for displacement of the border of the lungs, as well as the vital capacity, become gradually reduced until finally dyspnœa occurs on the slightest movement or even while the patient is at rest. Expectoration is often entirely absent even in these serious stages of the disease. The temperature is normal. Finally, there may occur marked symptoms of cardiac insufficiency with stasis of the pulmonary and general circulation. This state is responsible for the death of the patients. Clinically the picture presented up till the end in such cases is that of the purely silicotic lung.

Anatomically there may be found a fibrotic, in part hyaline, tissue which reveals no signs of tuberculosis infection, and likewise in animal experiments shows no connection with tuberculosis. In yet other cases, even when during life no symptoms of tuberculosis, were present, post-mortem examination reveals at the same time histological tubercular changes, and it may ultimately occur that the histological examination reveals no tuberculosis, whilst animal experiment and cultures show positive results. The possibility must therefore be admitted that, at least in some of the fibrotic cases showing large nodules but developing clinically, without symptoms of tuberculosis, latent tuberculosis infection nevertheless plays a part.

Very frequently there occur grave cases of silicosis in which, after long observation, definite tuberculosis is seen during life to be associated with silicosis.

There are often seen on the Röntgen plate, showing finely mottled silicosis, on one side in the upper part large spots with a tendency to spreading and cavitation. Such areas almost always develop later into overt tuberculosis. In the case of forms of silicosis with large mottling it is often very difficult to tell from the Röntgen picture whether overt tuberculosis is in course of development. A preference for the apical zones, asymmetry of the thickening processes, cavernous destruction and a small and vertical form of the heart, are indications of this state, but fairly often the Röntgen picture provides no differential criteria.

Clinically, loss of weight, night sweats, reduced strength, fever, occurrence of increased dullness, bronchial murmur, resonant rales in the apical zones, acceleration in the sedimentation test, are signs of active tuberculosis. Proof of the presence of the tubercular bacillus is often provided by animal experiment earlier than microscopically. A positive local and general reaction to tuberculin may on occasion be of value for the diagnosis of an active form of tuberculosis, but in general the tuberculin reaction and likewise the complement fixation test is of no great diagnostic significance in regard to the foregoing questions.

Koelsch [1] and Kaestle [2] designate the stage of fine mottling as the first stage of silicosis, associated with slight dyspnœa after effort.

The second stage is connected with the formation of larger and thicker foci and is characterised by increasing breathlessness, pressure and stitch in the chest, dry morning cough and a tendency to obstinate catarrh arising from cold.

To the third stage there belong forms with extensive and massive shadows, clinically marked dyspnœa, strong intense fits of coughing frequently accompanied by expectoration which is often slight, pains in the chest and disturbance of the circulation. The above distinctions have also been accepted by other research workers (Von Döhren [3], Reichmann [4] and Schürmann [5]). Still further investigators have likewise distinguished three stages, which do not, however, correspond to the above.

Thus where an exchange of views is desirable it is advisable—at least so long as no uniform designation has been established—to avoid the classification into first, second and third stages, and preferable to designate the dominant characteristics of each stage.

Course of the Disease

Extensive observations in the various dusty trades are still lacking in this connection. Böhme reports on the course of the disease during a certain number of years (two to eight) as affecting

---

[1] Koelsch: "Schwere Staublungenerkrankungen", in *Arbeit und Gesundheit*, No. 12, Ausdehnung der Unfallversicherung auf Berufskrankheiten, Berlin, 1929.

[2] Kaestle, in *Fortschr. auf dem Gebiete der Röntgenstr.*, 1928, Vol. XXXVII.

[3] Von Döhren: "Zur Klinik der Staublunge" in *Die gewerbl. Staublungenerkrankung*, Berlin, 1929.

[4] Reichmann: "Ueber die Begutachtung der Gesteinstauberkrankung", *ibid.*

[5] Schürmann: "Gewerbestaub, seine Bekämpfung, usw.", *ibid.*

150 stonecutters in the Ruhr coalfields. He confirms the gradually deteriorating condition of many silicosis cases after quitting work in dusty trades, observed by the South African investigators and the frequent development of these into serious forms of open tuberculosis. Of those showing incipient induration after two and a half years, about 26 per cent. had grown worse, and in a third of these active tuberculosis was confirmed. In cases of the typical fine mottled stage of the disease, after about two and a half years there was observed in 40 per cent. of the cases an increase in induration, and about a third of these showed active tuberculosis. Amongst those cases showing large hard masses of cicatricial tissue there was altogether an increase of induration amounting to 72 per cent., whilst overt tuberculosis was confirmed in half of these cases. The presence of tuberculosis was often established by means of experiments on guinea-pigs earlier than microscopically. Where, in the case of serious modifications due to dust, overt tuberculosis supervened, death usually occurred within a few years. Also in the case of slight changes due to dust, overt tuberculosis mostly followed a progressive course, though extensive improvements were also encountered. As a result of observation continued for several years, it was not infrequently remarked how, together with a state of general well-being, indurated centres gradually suffered extension and suddenly revealed cavernous formation with expectoration of the tubercular bacillus. Such observations point to the fact that already at an early stage the tubercular infection is latent in these indurated foci. Dust tuberculosis would appear to develop often for a period of years in the form of slow progressive indurated latent tuberculosis. The state of the patients is characterised by general well-being and freedom from toxic symptoms. Probably the blocking of the lymphatic channels prevents rapid dissemination of the infection and resorption of toxic substances. There finally occurs, nevertheless, in these advanced cases, collapse of the tissue and overt tuberculosis. Only in the minority of the cases does the process come to a complete standstill. Also in the finely mottled forms of silicosis lengthy observation often results in establishing definitely associated tubercular infection. Radiographically, such cases are characterised by forms showing larger apical or sub-apical foci, which mostly reveal a decided tendency to progress.

Our continued clinical observations have resulted in confirmation of the South African views as to the great significance of tuberculosis in regard to the production and progress of serious forms of silicosis.

On the other hand, clinical and anatomical investigations (see below) lead to the view that even serious and extended processes of induration *may* occur subsequent to the inhalation of quartz dust alone, and that such processes may, even after the patient has quitted the dusty trade in question, show continuous development up to a point at which, as a result of increasing pulmonary fibrosis, cardiac insufficiency of the right heart occurs, which leads to death by symptoms of stasis.

The association of silicosis and tuberculosis would often appear to follow a more favourable development than in the case of the stonecutters whom we had under observation. Kreuser reports on pottery workers who for decades showed overt tuberculosis. Holtzmann and Harms [1] and Roessle [2] speak of the benign nodular development of dust tuberculosis amongst pottery workers. Ickert [3] makes similar observations in regard to miners in the Mansfeld ore district.

Anatomical Research

Since the research engaged in by Arnold, fibrosis due to dust has in general been recognised as a disease *sui generis* and distinguished from tuberculosis. It has, however, been admitted on all sides that very often tuberculosis is associated with dust fibrosis. Nevertheless, the majority of Germans are of opinion that in this case these two processes are to be sharply distinguished one from another, and that dust inhalation, as such, may lead to extensive pulmonary fibrosis without associated tubercular infection.

Schmorl [4], Staub-Ötiker [5], Arai [6], Koopmann [7], Böhme and Schridde describe such cases of pure silicosis of serious development in which careful macroscopic and microscopic examination yielded no signs of tuberculosis.

Schridde [8] emphasises the histological similarity which exists between dust fibrosis (stone) with cicatricial keloid, and modifications of the ulcus callosum ventriculi, and assembles these processes

---

[1] Holtzmann and Harms: *Zur Frage der Staubeinwirkung auf die Lungen der Porzellanarbeiter.* Tuberkulose-Bibliothek, 1923, No. 10.

[2] Roessle, in *Beitr. z. Klinik d. Tuberkulose*, Vol. XLVII, No. 2.

[3] Ickert: *Staublunge und Tuberkulose bei den Bergleuten des Mansfelder Kupferschieferbergbaues.* Tuberkulose-Bibliothek, 1924, No. 15.

[4] Rostoski, Saupe, Schmorl: *Zeitschr. f. Krebsforschung*, 1926, Vol. XXIII.

[5] Staub-Ötiker, in *Archiv f. klin. Med.*, 1916, Vol. CXIX.

[6] Arai, in *Virchows Archiv*, 1920, Vol. CCXXVIII.

[7] Koopmann, in *Virchows Archiv*, 1924, Vol. CCLIII, p. 423.

[8] Schridde, in *Klin. Wochenschr.*, 1928, p. 582.

under the name of " keloidosis ". He sees in keloidosis a particular reaction of the connective tissue to simultaneous physical and mechanical irritation in subjects with a special inborn susceptibility. Böhme finds in about two-thirds of the sections oi lungs affected by dust an accompanying active tuberculosis, and in about one-third pure modifications due to dust without tuberculosis. In several cases, designated anatomically as pure dust fibrosis of serious development, the guinea-pig experiment gave negative results. In one or two cases in which clinically and anatomically no signs of tuberculosis were discerned, animal experiments and culture of tuberculosis bacillus gave opposite results.

In opposition to these views, Ribbert[1] had at an earlier date advanced an opinion that all indurated anthracotic nodules of the lungs in the hilar lymph glands owed their production, not to dust alone, but to simultaneous chronic infection, chiefly with tubercular bacillus. Merkel[2] also has concluded from his anatomical findings that simultaneous inhalation of dust and tubercular bacillus occurs and that these exert a double action in the production of the majority of dust fibrosis.

Hübschmann[3], similarly on the basis of histological research, holds the opinion that at least all extensive processes of hard cicatricial tissue in dust fibrosis are due, not to dust alone, but to the simultaneous influence of the tubercular bacillus, and even in cases in which small nodules are present, he found many to be of a typically tubercular character, and alongside this, transition to pure hyaline nodules, so that he also assumes tubercular ætiology for small nudolar forms of the disease.

Ickert[4], like Mavrogordato, distinguishes two varieties of small nodules: the majority are small fibrotic nodules, in the midst of which a blood-vessel is situated. These he calls block nodules, and attributes them to the influence of dust. Besides these nodules, there are found nodules similar in formation to the so-called " Puhl focii ", in connection with the production of which an infectious agent plays its part. Thus, though opinions differ in relation to the significance of tuberculosis in regard to the development of serious forms of dust fibrosis, it is nevertheless generally recognised that fine nodular modifications may arise purely from

---

[1] Ribbert, in *Deutsche med. Wochenschr.*, 1906, p. 1615.
[2] Merkel, in *Deutsches Archiv f. klin. Med.*, 1888, Vol. XLII.
[3] Hübschmann, in Ickert: *Staublunge und Tuberkulose bei den Bergleuten des Mansfelder Kupferschieferbergbaues.* Leipzig, 1924.
[4] Ickert: *Staublunge und Staublungentuberkulose.* Berlin, 1928.

the effect of dust. It is likewise admitted that also in many cases of serious silicosis, success has not attended any method of establishing proof as to the presence of tubercular infection, including also animal experiment.

As a consequence of serious pulmonary fibrosis, there is often met with in pure cases of lungs affected by dust a considerable dilatation and hypertrophy of the right ventricle, and also symptoms of stasis in the general and pulmonary circulation. The nutritional condition and the strength of the patient in such cases often remains very good up till death.

Our workers in dusty trades are exposed to very considerable injuries from dust, and there is therefore frequently found on dissection forms such as were frequently met with formerly in South Africa, though at the present time as a consequence of the successful campaign against dust, such forms have become much rarer in the above-mentioned country.

It has always struck the workers in dust fibrosis research that in cases of dust fibrosis complicated with tuberculosis very slight specific tubercular changes are to be found in the areas containing hard cicatricial tissue, and that the extensive fresh tubercular focii are met with rather in those parts of the lung which are free from fibrosis. Likewise in the bronchial glands there are often no large tubercular modifications to be found. Fränkel [1] has already regarded as the cause of this phenomenon the block of the lymph passages by dust induration, which prevents transport of the tubercular bacillus and causes the tubercular process to be limited for a long time to one spot, and to develop chronic induration. Jötten and Arnoldi have confirmed by their animal experiments this blockade of the tubercle bacillus. Roessle [2] attributes only slight importance to the lymph block. He is rather inclined to the view that a specific influence on the connective tissue peculiar to silicic acid, is the cause of the fibrotic character of dust tubercles, and is even in favour of the therapeutic application of silicic acid as a remedy against pulmonary tuberculosis.

While the block of the lymph vessels on the one hand obstructs the spread of the tubercular processes, on the other it hinders the cleansing mechanism of the lung from acting in rejecting tubercle

[1] Fränkel: *Spezielle Pathol. u. Therapie der Lungenkrankheiten.* Berlin, 1904.
[2] Roessle, in Brauer: *Beitr. z. Klin. d. Tuberk.*, Vol. XLVII, 1921.

bacilli and other infectious agents which have penetrated it, and so provides, perhaps, the explanation of the increased tendency of cases of dust fibrosis to develop tubercular infection (Fränkel).

Schneeberg Lung Disease

A disease of special character, connected with the inhalation of stone dust, is the Schneeberg lung disease, a combination of dust fibrosis and cancer of the lungs which has been frequently observed amongst the miners in the Schneeberg Mines on the borders of Saxony and Bohemia. As the researches of Rostoski [1], Saupe and Schmorl in confirmation of former observations prove, about one-half of the older miners die of this disease. The condition in question is pulmonary carcinoma, of slow and partly horny growth inside the pneumoconiotic lung with metastases in the hilar gland and partly also in other organs. Amongst the population of the district not occupied in the mines, such frequency of pulmonary carcinoma is not met with, and it must therefore be induced by the occupation in question. One condition necessary to its production is dust induration, but this is not the only condition. Frequency of pulmonary carcinoma has, indeed, in the last decades, been by many authorities (Von Hampeln, Schmorl [2]) stated to be related to increase of dust due to industrialisation and traffic. It should, however, be noted that in other industrial regions, as, for example in the Ruhr district, in spite of the frequency of diseases due to dust, complication with pulmonary carcinoma has hardly been noticed. As a further condition for the production of pulmonary carcinoma in the case of Schneeberg disease, there have therefore to be taken into account certain properties of the ore extracted there. The ore in question is chiefly cobalt and bismuth, with an arsenic and radium content. It is just this mixture of arsenic and radium which is perhaps of significance. It is recommended in every case where ore with a radium content is extracted, that attention should be paid to the possible presence of pulmonary carcinoma. The practical importance of the Schneeberg lung disease is at present not great, as the number of workers engaged in the local mines is diminishing considerably, and hardly exceeds fifty. Its theoretical interest, however, is all the more important.

---

[1] Rostoski, Saupe and Schmorl, in *Zeitschr. f. Krebsforschung*, 1926, Vol. XXIII.
[2] Von Hampeln, in *Grenzgeb. d. Med. u. Chir.*, 1922, Vol. XXXVI.

Experimental Silicosis

Lehmann [1] and his pupils Saito, Gfrörer, and Katayama [2] proved by animal experiment that about 50 per cent. of inhaled dust is retained by the nasal mucous membrane. A further amount is retained by the walls of the bronchial tubes, and withdrawn thence by the action of the ciliated epithelium into the pharynx, whence it passes into the digestive canal. Only 4 to 24 per cent. of inhaled dust arrives in the lungs.

The older investigations in regard to experimental production of pneumoconiosis, including those of Arnold, were mostly undertaken with very considerable quantities of dust, which greatly exceeded those which have to be taken into consideration in connection with human pathology. Acute injuries resulting from dust were caused by these large amounts of dust, especially bronchopneumonia, which, at first of a secondary order, ultimately led to fibrosis, which cannot be directly compared with human fibrosis without further investigation. Pure inhalation experiments with small measured quantities of dust gave—in the absence of infections—hardly any, or very slight, reactive fibrotic processes.

Gross [3], using a mixture of soot and quartz dust for inhalation in the case of rabbits, failed entirely to produce fibrosis. Lehmann made cats and guinea-pigs inhale for a considerable time porcelain dust in concentration similar to that inhaled in the porcelain industry. In this case likewise no fibrotic changes took place.

Cesa-Bianchi [4] instituted experiments in regard to the signification of simultaneous tubercular infection. The dust concentrations used by him, though very considerable, were not, in themselves, sufficient to produce notable histological modifications, apart from a few cases of pneumonia. The animals previously subjected to dust were thereafter infected with small amounts of weakened cultures of the tubercular bacillus. These animals almost all died of tuberculosis of the lungs of a grave form, whilst the infected control animals which had not been previously subjected to dust, showed no tubercular modifications, or very slight tubercular affections. In these cases, tuberculosis was therefore obviously favoured by dust inhalations. Chalk and gypsum dust had less effect than grindstone dust and anthracite dust.

---

[1] Lehmann, Saito and Gfrörer, in *Archiv f. Hyg.*, Vol. LXXV.
[2] Katayama, in *ibid.*, 1916, Vol. LXXXV.
[3] Gross, in *Beitr. z. Pathol. Anat. u. z. allgem. Pathol.*, 1927, Vol. LXXVI.
[4] Cesa-Bianchi, in *Zeitschr. f. Hyg. u. Infektionskrankh.*, 1913, Vol. LXXIII.

Henius and Richert [1] did not succeed in proving the influence of the inhalation of coal dust on rabbits infected with tuberculosis.

Wedekind [2] has, on the other hand, observed arrest of tuberculosis of the lungs in the case of rabbits infected intravenously, through previous or subsequent intravenous injection, of the suspension of coal dust.

Remarkable progress was effected by the large-scale experiments of Jötten [3] and his collaborators, whose methods are distinguished from those of earlier research workers especially by exact dosage of the dust used, and by the method of infecting with tubercular bacillus. After intensive dusting during two to five months with fired vitrified porcelain dust, the laboratory animals showed a highly developed proliferating reaction of the endothelium of the capillaries of the lungs, which induced serious disease and eventually death. The dust was found on the mucous membrane of the respiratory passages, in the alveoli, in part filling these out completely, in the inter-alveolar and inter-lobular tissues, in the peribronchial, perivascular and sub-pleural tissues, and in the tracheo-bronchial lymph nodules. The greater part of the dust formed an inter-cellular deposit. Fine unfired porcelain dust of almost similar SiO_2 content, but richer in kaolin and coal dust, caused qualitatively similar, but much slighter modifications. Two months after the inhalation had stopped, the coal dust had for the most part disappeared from the lungs, whilst the porcelain dust was firmly fixed therein.

With a lesser concentration there appeared, even after use of fired porcelain dust, no particular symptoms of disease. The septa were somewhat thickened in parts through cell proliferation, and there was also a slight fibrosis of the septa. The dust deposit was similar to that in the previous case, but smaller.

After inhalation of lime dust, lime particles were found in the lungs only in very sparse amount. Lime was immediately and completely dissolved.

By application of massive concentration of dust, the changes in the lungs brought about by dust alone were therefore very slight. In order to study the effect of dust inhalation on simultaneous tubercular infection, the rabbits were subjected to an intertracheal infection with droplets by means of spraying with a tuberculous bacillus emulsion. In one part of the experiment, a striking similarity

[1] Henius and Richert, in *Zeitschr. f. Tuberk.*, 1926, Vol. XLVI, No. 2.
[2] Wedekind, in *Klin. Wochenschr.*, 1928, No. 19.
[3] Jötten and Arnoldi: *Gewerbestaub u. Lungentuberkulose.* Berlin, 1927.

to the conditions in the case of human beings was encountered in the following manner: the animals were first subjected to a weakened infection by the use of drops, and later, after or during prolonged dust inhalatiön, were reinfected with a stronger intravenous dose of tuberculous bacillus. It was found that with the exception of lime dust, all the kinds of dust applied favoured the settling and dissemination of the tuberculosis infection. The danger of various kinds of dust is given in descending order in the following series: steel grinding dust, coarse pottery dust, fine pottery dust, coal dust and soot. The last two were indeed probably less harmful than grindstone and pottery dust, but showed, however, in contrast to the controls, an undoubted favouring of tuberculosis, an observation which is of importance in the face of many statements to the contrary, which are mostly based on insufficient material. The most dangerous kinds of dust are those rich in quartz. They are distinguished by the fact that they are retained in a considerably firmer manner by the lung tissues than coal and soot. Lime (CaO_2H_2) inhalation does not favour tuberculosis infection—it may even perhaps be said to give rise to a certain arrest of the process. In the case of animals reinfected with porcelain dust, there occurs a marked tendency to the development of connective tissue round the tubercular focii, as is characteristic in the case of human beings where there is a combination of injury due to dust and tuberculosis.

Jötten and Arnoldi consider, as also did Fränkel at an earlier date, the obstruction of the lymph channels by dust as of importance in the causation of the unfavourable effect of dust on the progress of tubercular infection. The lymphatic system in the presence of dust-fibrosis is consequently no longer in a position like the dust-free lung—to effect its task, namely, to reject disease stimulants which have penetrated into it.

The results of research are in accord on many points with those established by Mavrogordato, but indicate further an effect, though a slight one, of coal dust and soot in favouring tuberculosis.

Later, similarly conducted experiments by Jötten and Kortmann [1] have shown that stone dust, with a 57 per cent. silicic content (SiO_2) applied to prevent coal dust explosions in mines, produces a similar effect to the fired porcelain dust, whilst cement dust (20 per cent. SiO_2) and limestone dust only slightly favoured tubercular infection, and basic slag dust not at all.

---

[1] JÖTTEN and KORTMANN: *Gewerbestaub und Lungentuberkulose.* II. Teil. Berlin; Springer, 1929.

Chemical Experiments

Chemical experiments show that where pneumoconiosis is present to a considerable extent, silica has been deposited in large quantities in the lungs. Böhme, in examining rockdrillers' lungs, has found a close relation to exist between the amount of deposited silicic acid and the gravity of the fibrosis. Where the quartz content (and silicates) of the fresh lung substance amounted to over 0.7 per cent. (reckoned as dry substance over 3 per cent.), there was found an extended cicatricial fibrosis, with quantities ranging between 0.3 and 0.6 per cent. a moderate or average extent of fibrosis, and with smaller quantities of quartz very little or no fibrosis. Even in the same lung, the more seriously indurated centres proved to be richer in quartz than the less indurated parts. The highest quartz content found in a rockdriller's lung was 2.25 (calculated as fresh substance) or 8.77 per cent. (calculated as dry substance). The value is almost as high as that formerly found by Langguth in the case of a haematite cutter, namely, 11.9 per cent. (calculated as dry substance), the highest amount known to me in medical literature. The silicon is contained in the acid insoluble fraction of the silicotic lungs not only in the form of SiO_2, but in smaller portions also as aluminium or alkali silicate. We find in the hydrochloric acid insoluble fraction, 74 to 83 per cent. SiO_2, 13 to 22 per cent. Al_2O_3, 3.7 per cent. alkali oxide together with small amounts of MgO or Fe_2O_3. The coal content of the silicotic miner's lung may be extraordinarily high, up to 5.44 per cent. of coal reckoned as damp substance (21 per cent. as dry substance). In the case of serious pneumoconiosis affecting graphite millers, Koopmann [1] found 12.93 per cent. of graphite (reckoned as dry substance). On the other hand, amounts of 1.4 per cent. of coal (reckoned as wet substance) were supported without reaction by the lung tissues.

Infectiousness of Dust Tuberculosis

All doctors in districts where dangerous dusty trades have been carried on have for centuries back (Agricola) noticed that a high mortality rate from lung diseases amongst the men was accompanied by a considerably lower mortality rate for the women and children. It has been concluded therefrom that dust-tuberculosis is but slightly infectious. This fact is indeed explained by the widely

[1] Koopmann, in *Virchows Archiv*, 1924, Vol. CCLIII, p. 423.

recognised poverty in bacilli of the sputum, yet recent accurate observations have nevertheless shown that the frequency of tuberculosis amongst women and children in the families of workers in dusty trades is higher than the average; Ickert [1] and Redeker [2] have found by radiological examination of the children of Mansfeld miners a frequency of cases of calcified tubercular focii in the lung amounting to twice that for children in the other industrial areas, and further, that active tubercular forms occurred five times as frequently amongst the schoolchildren in the Mansfeld mine districts as in the surrounding country districts. According to Kreuser [3], the tuberculosis mortality amongst members of the families of pottery workers is distinctly higher than that for women and children belonging to the families of other workers in the same area (3.1 as opposed to 1.7).

Incidence of Silicosis

There are not so far available research results which embrace the total number of workers engaged in any given industry, yet an extensive series of observations has already been furnished in regard to many industries.

Rockdrillers in Mines

Silicosis is met with more rarely amongst the coal miners in the Ruhr coal district, but on the other hand, more frequently amongst the rockdrillers engaged in drilling the layers of stone situated between the beds of coal, blasting the stone, and removing the debris. Amongst hese rockdrillers silicosis has considerably increased subsequently to the introduction of mechanical drills, as a consequence of the larger amount of dust produced. At the instigation of the Ruhr Miners' Society (Ruhr Knappschaft), there was undertaken in the winter of 1928-1929 clinical and radiological (plate of the lungs) examination of 3,318 rockdrillers working in the mines, in order to determine the presence of alterations due to dust. According to Schürmann [4], of the above workers:

1,261	had	worked	as	rockdrillers	for	5	years
1,095	,,	,,	,,	,,	,,	10	,,
441	,,	,,	,,	,,	,,	15	,,
305	,,	,,	,,	,,	,,	20	,,
216	,,	,,	,,	,,	,,	25	,,

[1] Ickert: *Staublunge und Staublungentuberkulose.* Berlin, 1928.
[2] Redeker, quoted by Ickert.
[3] Kreuser, in *Beitr. z. Klinik der Tuberkulose*, 1926, Vol. LXIII.
[4] Schürmann: "Gewerbestaub", in *Die gewerbliche Staublungenerkrankung.* Berlin, Springer, 1929.

Of these 3,318 individuals, 80.56 per cent. showed no modifications due to dust, 19.44 per cent. showed modifications due to dust distributed as follows:

	Per cent.
Slight alterations	14.74
Alterations of slight to average severity	2.26
Alterations of average severity	1.84
Alterations of average severity to grave alterations	0.42
Grave alterations	0.18

Examinations made by Böhme amongst working rockdrillers provided similar figures. Greater accumulation of indurated symptoms due to dust is found only after about ten years' occupational experience, but even after five years and, exceptionally, after two years changes of average severity are to be met with. Investigations amongst working rockdrillers do not comprise all severe disease forms, since the victims of these have mostly been already obliged to give up work. Such cases are much more frequently encountered in the course of investigations covering miners suffering from diseases of any kind in hospitals. Likewise the frequency of pneumoconiosis is naturally considerably greater amongst these, since workers with pronounced dust diseases are to be found assembled in the hospitals, and whilst, as a result of the high average age of hospital patients, many workers formerly suffering from latent silicotic disease have at those ages passed into the stage of overt silicosis. Böhme found, during an examination of 301 rockdrillers in a hospital in the last three years, the following figures:

TABLE I

Length of employment on rockdrilling	Number of workers examined	Incipient to slight silicosis	Silicosis of average severity	Severe silicosis	Total
Years					
10	124	41	10	5	56
10–20	133	54	15	7	76
20–30	34	11	7	4	22
Over 30	10	1	2	3	6
	301	107	34	19	160

From this survey there is easily recognised the increase in more serious forms accompanying duration of employment at rockdrilling.

The occurrence of dust fibrosis at all stages amongst rockdrillers is also reported from other German coal districts (Upper Silesia and the Saar district), though statistical data in regard thereto are not so far available; likewise, the presence of silicosis is known amongst ore miners in the Saar and in the Mansfeld mines.

Ickert [1] observed exceptionally, even after two to five years, typical changes; but extensive fibrotic forms only after at least ten years.

In the Mansfeld copper district the mortality rate from tuberculosis is, according to Redeker (quoted by Ickert) three times as high for the men as for the women. The tuberculosis mortality rate reckoned over 10,000 living units, amounts in the local mining communities to 36.5 as opposed to 10.7 in the other Prussian country districts. The peak of the mortality rate for the local miners, and indeed for general affections as well as for tuberculosis, lies between fifty and sixty years of age, that is to say, as high as that for all dangerous dusty trades.

Böhme met with an overt form of tuberculosis amongst rockdrillers having completed over ten years of employment, at the rate of 3.5 times as frequent as that for coal miners with a similar period of employment.

Quarry Workers

According to Domann [2] there were in 1907 70,000 workers engaged in stone quarries and in establishments for the manipulation of stone.

Thiele and Saupe [3] have found amongst quarry workers in the Elbe sandstone district changes due to dust amounting to a very high percentage. This depends on the one hand on the very high quartz content of the stone, and on the other on the fact that victims of dust still continue to work in the dusty trades, whilst in the coal districts they are removed from work on rockdrilling as soon as possible after they are found to be suffering from the disease in question. Tuberculosis is often found in combination with dust fibrosis amongst the sandstone workers in Saxony. Table II again provides statistical data.

---

[1] ICKERT: *Staublunge und Staublungentuberkulose.* Berlin, 1928.

[2] DOMANN: *Die Steinhauerlunge.* Veröffentl. aus dem Gebiete der Medizinalverwaltung. Berlin, 1925.

[3] THIELE and SAUPE: *Die Staublungenerkrankung der Sandsteinarbeiter.* Berlin, 1927.

TABLE II

Length of employment Years	Number of workers examined	Injuries due to dust		
		Slight	Average	Severe
Up to 5	9	1	–	–
,, ,, 10	9	1	2	–
,, ,, 15	8	6	1	–
,, ,, 20	19	13	4	–
,, ,, 25	19	10	6	1
,, ,, 30	24	9	11	4
,, ,, 35	10	4	4	2
,, ,, 40	11	1	10	–
,, ,, 45	2	–	–	2
,, ,, 50	1	–	1	–
	112	45	39	9

Kaestle[1] found, among 40 variegated sandstone workers, 25 suffering from silicosis, and amongst 133 white sandstone workers 38 suffering from silicosis. Amongst the variegated sandstone workers silicosis was not only more frequent but occurred oftener in the severer forms, whilst amongst the white sandstone workers the slight forms predominated. The sandstone worked contained about 80 per cent. of crystallised SiO_2. Kaestle draws attention to the fact that the isolated focii induced by this particularly quartzitic dust were distinguished radiographically by the depths of the shadows and the sharpness of the border lines. Nürburg siliceous chalk contains 89 to 97 per cent. of quartz, mostly in an amorphous form. Among 39 workers, who, moreover, had been employed at the most for fifteen years, 8 were found to be suffering from dust fibrosis[2].

Amongst 93 granite workers (30 per cent. SiO_2) only 7 suffered from coniosis. Tuberculosis was suspected only in 2 cases.

Kaestle found, among other symptoms, amongst shell limestone workers (SiO_2 practically nil) inflamed hilar glands and sparse pulmonary focii with small mottling, but none of the changes corresponding to true silicosis and no tubercular lesions.

Cement Workers

The cement industry in Germany gives employment to 25,000 workers (Beintker)[3].

[1] Kaestle, in *Fortschr. d. Roentgenstrahlen*, 1928, Vol. XXXVIII, No. 6.
[2] Kaestle, *loc. cit.*
[3] Beintker: "Zementfabriken und Kalkbrennereien", in *Handbuch der sozialen Hygiene*, 1926, Vol. II. Berlin.

Cement contains about 19-22 per cent. SiO_2, 62-65 per cent. CaO, 7-9 per cent Al_2O_3. The silicic acid is for the most part contained in a fixed form, only 3 per cent. being free SiO_2 (Jötten)[1]. According to Schott[2], cement workers seldom develop indurated dust focii of the lungs, and then only after ten years' employment. Out of 100 cases, mostly older workers, he found changes due to dust in 21 cases, which for the most part were of a slight variety. Kaestle, on examination of 93 cement workers, found only one typical case of pulmonary silicosis; in five further cases there were slight changes of the hilus and surrounding areas, which he likewise attributed to the effect of dust. The tendency to tubercular changes could not be proved. The tuberculosis mortality rate amounted in 1908 to 10.6 per 10,000, and was therefore very small. Perhaps the lime content of the cement exercises a favourable influence as regards tuberculosis. Sleeswijk[3] emphasises the fact that in the Dutch sandstone works the risk to the workers diminishes, the greater the lime content of the stone. The low tuberculosis mortality rate of marble-workers, plaster-burners and other workers handling materials with a lime content is known (Jötten and Arnoldi). The quantity of dust in the cement industry is in parts considerable, despite many measures of protection. Jötten found in the packing-room 20 mg. of dust per cubic metre, near the cement mills 160 mg., and near the ball mills 300 mg.

Quartz Millers

Injury due to dust is set up to a considerable extent in the case of quartz millers[4].

Pottery and Stoneware Industries[5]

According to Koelsch (1914), there were 67,295 workers and employees engaged in the German china industry. Only about half of these were employed in connection with the production of china and exposed to china dust in large quantities. The other half consisted of decorators and helpers (painters, packers, machine workers, etc.); 25 to 40 per cent. of the employees were women.

---

[1] JÖTTEN: "Staublunge und Staublungentuberkulose", in *Die gewerbliche Staublungenerkrankung*. Berlin, 1929.

[2] SCHOTT, in *Beitr. z. Klinik der Tuberkulose*, Vol. LXIX, No. 1.

[3] SLEESWIJK, in *IV. Internat. Kongress für Unfallheilkunde und Berufskrankheiten*, Amsterdam, 1925.

[4] DOMANN, *loc. cit.*

[5] LEHMANN: *Ueber die Gesundheitsverhältnisse der Arbeiter in der deutschen keramischen, insbesond. der Porzellanindustrie usw.* Berlin, 1929.

The clay used contained about 25 per cent. quartz, 25 per cent. feldspar, and 50 per cent. kaolin (aluminium silicate). Froboese [1] found quantities of dust amounting to 3.5–161 mg. per cubic metre. The higher quantities were almost always found in the grinding rooms; in the other departments the quantities of dust for the most part only amounted to 5-20 mg., or on an average to 12.3 mg. Koelsch had at an earlier date found greater quantities. The installation of the factories was in general designated as hygienic. At points where there was more abundant dust production many kinds of exhaust apparatus had been successfully applied, as in the cases of polishing half-dry china objects, cleaning subsequent to first firing, kiln drawing, glazing, etc.

Holtzmann and Harms [2] found on radiological examination of 41, chiefly older, pottery workers, 19 cases of coniosis of average to severe type, and in three cases the symptoms of pronounced pneumoconiosis.

Examination of 85 workers belonging to china factories in Berlin revealed about 30 per cent. of the workers as suffering from changes due to dust. May and Petri [3] examined radiologically 50 elderly pottery workers particularly exposed to the inhalation of dust, and suspected of clinical symptoms, and found slight thickening in the hilar area in 30 per cent., with incipient mottling in 26 per cent. and distinct mottling in 12 per cent. According to the extensive and protracted researches undertaken by Koelsch and Kaestle [4] at Selb, the chief centre of the Bavarian pottery industry, 145 out of 455 porcelain workers, or about one-third, revealed radiologically symptoms of dust fibrosis, mostly of a slight degree, and a smaller number in the second and third degree. The male workers suffered more frequently (38 per cent.) from changes due to dust than the women (25 per cent.). The reason for this difference is chiefly to be found in the shorter length of employment in the case of women.

In 1.5 per cent. of the total number cirrhotic tuberculosis was confirmed, and the possibility of a combination of dust fibrosis and tuberculosis was admitted in a further 3.7 per cent. A frequent tuberculosis rate could therefore not be proved.

---

[1] Froboese, in *Archiv f. Hygiene*, 1925, Vol. XCV, p. 175.

[2] Holtzmann and Harms: *Zur Frage der Staubeinwirkung auf die Lunge der Porzellanarbeiter.* Tuberkulose-Bibliothek, No. 10. Berlin, 1923.

[3] May and Petri: *Beitr. z. Klinik d. Tuberkulose*, 1924, Vol. LVIII, No. 2.

[4] Koelsch and Kaestle: *Klinische und röntgenologische Untersuchungen über den Lungenbefund bei 500 Porzellanarbeitern.* (Not yet published, quoted by Lehmann.)

Amongst the helpers in the pottery industry no forms of indurated tissue due to dust were met with.

Earlier statistical returns prepared by Sommerfeld [1], Holitscher[2], Bogner [3], Leymann [4], Koelsch [5], all concurred in showing a high tuberculosis mortality amongst porcelain workers. At least, any variations were slight. On the basis of clinical researches Koelsch had earlier, in 1908-1912, found a higher morbidity rate for tuberculosis, and likewise Thiele [6] in 1920 in regard to the Saxon porcelain workers. Kreuser [7] also, in his capacity of insurance medical officer for the district of Merzig finds frequent causes of death from overt tuberculosis amongst pottery workers. The annual tuberculosis mortality rate per thousand amounted amongst the pottery workers to 4.4 per cent., and amongst other workers to 1.77 per cent.

The peak of the tuberculosis mortality rate among porcelain workers was reached, according to Kreuser, between the ages of fifty-one and sixty, whilst for the remainder of the local population the peak rate occurred between twenty-one and thirty. Thiele, Koelsch, Holtzmann and Harms find a similar age for the peak rate.

That the occupational risk is not the only decisive factor in regard to the tuberculosis mortality rate among porcelain workers has been shown by Vollrath [8] in a statistical work. In the various porcelain districts of Thuringia the tuberculosis mortality rate amongst these workers is lowest where the economic and hygienic conditions are most favourable, and vice versa. Koelsch [9] also proved, in regard to the Bavarian industry, that tuberculosis is of most frequent incidence in those districts where the pottery industry has been longest established, the calling descending from father to son, and where conditions approach those of town industries, whilst in other regions, where the industry was of later establishment, the plant more modern, and the workers living in country surroundings, the tuberculosis was less disseminated. Pathological and anatomical researches have been engaged in by

[1] Sommerfeld, in *Deutsche Vierteljahrschr. für öffentliche Gesundheitspflege*, 1893, Vol. XXV.

[2] Holitscher : "Krankheiten der Porzellanarbeiter", in *Weyls Handb. d. Arbeiterkrankheiten*, 1908.

[3] Bogner, in *Deutsche Vierteljahrschr. f. öffentliche Gesundheitspflege*, 1909, Vol. XLI.

[4] Leymann, in *Zentralblatt f. Gewerbehygiene*, 1913 and 1915.

[5] Koelsch: "Staub und Beruf", in Grotjahn and Kaup, *Handbuch der sozialen Hygiene*, 1912.

[6] Thiele, in *Zeitschr. f. Tuberkulose*, 1921, Vol. XXXIV.

[7] Kreuser, in *Beitr. z. Klinik d. Tuberkulose*, 1926, Vol. LXIII.

[8] Vollrath, in *Beiträge zur Klinik der Tuberkulose*, 1921, Vol. XLVII.

[9] Koelsch: "Keramische Industrie", in *Handbuch der sozialen Hygiene*, Vol. II. Berlin, 1926.

Roessle of Jena. Out of 45 pottery workers, 20 (44 per cent.) were seen on post-mortem examination to have suffered from dust fibrosis, and 25 (50-55 per cent.) from tuberculosis.

From the fibrotic character of the tuberculosis of the lungs and the lack of caseous forms of pneumonia, Roessle[1] concludes that a favourable effect is exercised by porcelain dust.

The results of more recent researches undertaken amongst workers in the German pottery industries, are in agreement in proving that pneumoconiosis of the lungs occurs in a considerable number of cases. Controversy exists in regard to the question of whether tuberculosis is also frequent amongst these workers. Under favourable hygienic conditions, up to the present, incidence of overt tuberculosis has hardly been found to be above the average amongst workers engaged in the china factories. Kreuser's figures relative to the frequency of deaths from tuberculosis and those of Roessle relative to the incidence of tuberculosis as a factor in mortality amongst porcelain workers, point, on the other hand, to the fact that towards the end of life, tuberculosis occurred frequently amongst these workers. The contradiction between these points of view is only apparent. Probably many cases of fibrotic tuberculosis, which only became open late in life, have been disguised as dust fibrosis.

Metal-Grinders

The frequency of lung diseases amongst grinders has been recognised for a long time. Protracted hygienic, clinical and radiological researches have been recently instituted by Teleky, Lochtkemper, Rosenthal-Deussen and Derdack[2] in the highlands (Solingen-Remscheid district). Recognition of the connection between dust inhalation and lung disease had given rise to the introduction of regulations as to means of protection as early as 1875. Under the influence of these, and in connection with the general fall in the tuberculosis mortality rate, the health conditions amongst grinders has very considerably improved in Solingen, though less so in other places in the district.

In so far as the death registers permit of judgment of the circumstances, it was found that tuberculosis still occurred very frequently amongst grinders and that the rate was extremely heavy in certain

---

[1] Roessle, in *Beiträge z. Klinik d. Tuberkulose*, 1921, Vol. XLVII, No. 2.

[2] Teleky, Lochtkemper, Rosenthal-Deussen and Derdack: *Staubgefährdung und Staubschädigungen der Metallschleifer*. Berlin, 1928.

places. The tuberculosis mortality (inclusive of dust fibrosis) relative to 10,000 living, amounted in Solingen to 14.7 for the total male population, and 29.9 for the grinders. In Remscheid the differences were much greater. The tuberculosis mortality return for the male population amounted to 17.0, whilst on the other hand the corresponding rate for grinders reached 97.6. In Solingen as well as in Remscheid, a very remarkably high peak for tuberculosis mortality was revealed for workers of 50 years of age, as Collis and Teleky have frequently shown to be the case in regard to occupational tuberculosis. Very remarkable is the difference between the tuberculosis mortality for grinders in the two adjacent towns of Solingen and Remscheid. Teleky ascribes this to the difference between the hygienic conditions of the industry in the two places.

With the help of Owen's apparatus Rosenthal-Deussen and Teleky estimated the amounts of dust in various workplaces; they then established the fact that in winter the amount of dust was about three times as great as in summer, in consequence of the lack of ventilation and the production of soot from the heating apparatus. The result of comparative analysis at working posts can be seen from table III:

TABLE III. — ESTIMATIONS OF DUST IN GRINDING ROOMS [1]

Occupation	Dust figures at the working-post	
	Summer	Winter
Wet sandstone	1,047	2,546
Dry sandstone, with dust removal	785	
Artificial grindstone, dry, without dust removal	647	
,, ,, ,, with dust removal	246	
,, ,, ,, with mechanical removal	428	
,, ,, wet, automatic	203	
,, ,, ,, hand work	295	
,, ,, with oiling	605	
Dry emery polishing, without dust removal	419	1,424
,, ,, ,, with dust removal	244	
Fine emery polishing, without dust removal	358	
,, ,, ,, with dust removal	238	
Dry buffing, without dust removal	526	
,, ,, without dust removal, with oiling	674	
,, ,, with dust removal, with oiling	263	

[1] Rosenthal-Deussen and Teleky.

It follows from this that by far the greatest amounts of dust are developed during the wet grinding of sandstone—an established fact which is in accord with the findings of the English and American research workers. The dust figure is lower in the case of grindstones provided with ventilation apparatus, and likewise in the case of artificial grindstones and emery polishing.

The artificial grindstone consists of artificial corundum (Al_2O_3) or silicon carbide (SiC). Also emery (30-40 per cent. corundum, a little Fe_2O_3, 2-8½ per cent. SiO_2) is used. Emery polishing is effected by leather bands coated with emery (or colcothar, chalk, diatomaceous earths). The dust figure becomes considerably diminished by the application of exhaust devices during the use of artificial grindstones, and likewise during emery polishing. Oiling does not reduce the dust figure. During wet grinding on sandstone the dust produced is especially rich in quartz particles. Large amounts of dust arise during rounding and splitting of sandstone.

Lochtkemper examined clinically and radiologically 100 grinders, with a view to determining the presence of injuries due to dust. The results of this examination are given in table IV.

TABLE IV

	Number examined	Free form dust fibrosis	Suffering from dust fibrosis		
			I	II	III
Polishers	11	4	7	–	–
Fine emery polishers (pliester)	9	–	9	–	–
Dry emery polishers (pliester)	15	4	8	2	1 [1]
Artificial grindstone	14	2	10	2	–
Dry sandstone	15	4	1	8	2
Wet sandstone	36	–	19	6	11
	100	14	54	18	14

[1] Had worked for twenty-three years in the same room on wet grinding.

The classification of the three stages of the disease differs from the usual practice, in so far as that all cases evolving with thick, fine mottling are included in Group III; these have been recorded by other research workers as changes of slight—or, as the case may be, average severity.

The cases in the first group only show very slight changes. It is true that changes due to dust are found amongst all the groups of workers, but the very severe changes are found almost exclusively in the case of sandstone grinders, and here again, these predominate in the case of wet grinding.

Polishers, emery polishers, and artificial grinders show only increase of the linear marking of the lung with single mottling, and increased trunk shadows at the basis of the lung. When at all exposed to the influence of quartz dust, these groups of workers only come in contact with very small quantities.

Lochtkemper and Teleky recommend, amongst others, the following hygienic measures of improvement: substitution of artificial grindstones for sandstone as far as possible; separation of emery polishing rooms from the ordinary grinding rooms, and effective dust exhaust devices.

Various Occupations

The occurrence of a typical form of silicosis is known in Germany amongst workers producing and handling fireproof (with a quartz content) stone-ware (schamotte-silica-stone), amongst moulders in iron foundries who make the moulds for castings, amongst workers engaged in sand-blasting; and amongst glass-grinders. Statistical returns as to the frequency of silicosis amongst these workers are, however, still lacking.

Coal Miners (Hewers)

Among hewers in coal mines, also, radiological examination reveals, amongst other symptoms, slight indurated areas due to dust. The frequency of this affection may be seen from the following table, prepared by Böhme:

Length of employment Years	Number examined	Initial changes	Fine mottling	Appearance of the formation of hard cicatricial tissue	Severe thickening	Number of cases of indurated forms
0–10	24	0	1	0	0	1
10–20	94	16	9	0	0	25
20–30	74	17	9	0	0	27
30–40	31	12	9	1	0	22
	223	45	28	1	0	75

The frequency and intensity of the changes thus increases, as in other dusty trades, with the length of employment, but the disease hardly ever proceeds beyond the stage of fine mottling. Anatomical examinations have established that the condition in question consists of a true small nodular dust fibrosis. Often the cause may be sought in a mixture of quartz with the dust. The coal hewer may also, on occasions, inhale quartz dust which is produced in his neighbourhood, or which he himself raises in removing stones in his proximity. Large quantities of coal dust can, however, in themselves produce a certain form of fibrosis. The quartz content chemically proved to be present in such lungs with coal dust nodules is, however, extraordinarily low. Collis also has observed pneumoconiosis amongst coal miners, especially coal trimmers. In the least severe cases the Röntgen ray revealed changes consisting only in an increase in the linear marking of the lungs. Anatomically this stage often corresponds merely to the filling-up of the perivascular and peribronchial lymph areas with coal dust, without fibrosis worthy of mention.

Severe dust changes are at times observed amongst graphite workers. Quite pure and soft Swedish coal may indeed become deposited in considerable amount in the lungs, and give rise to a mottled X-ray picture, but according to Edling [1] it is not productive of fibrosis. Hollmann [2] found, amongst 33 workers in a carbon pencil factory exposed to pure coal and graphite dust without admixture of stone, three certain cases of dust fibrosis, and besides these, sixteen cases in a pre-fibrotic condition.

The mortality from tuberculosis among the miners in the Ruhr district was before the war, at the figure 71 per 10,000, less than that for most other occupations. During the War and after the War it rose considerably, and then gradually fell. It would be considerably less were not stonecutters, with their high tuberculosis mortality, included in the returns.

Legislative Provisions in regard to Compensation [3]

By an Order of the Ministry of Labour, dated 12 May 1925, a number of occupational diseases have been assimilated to occupational accidents for the purpose of compulsory compensation.

Silicosis was not at that time included under those occupational diseases subject to compulsory compensation, though the Schneeberg lung disease, that peculiar disease occurring amongst the miners of the Schneeberg ore district, which evolves with the formation of carcinoma in a silicotic lung was included.

[1] Edling, in *Acta radiologica*, Vol. VI.
[2] Hollmann, in *Zeitschr. f. Tuberkulose*, 1928, Vol. LII, p. 394.
[3] Cf. Bauer, Engel, Koelsch, Krohn: "Die Ausdehnung der Unfallversicherung auf Berufskrankheiten", in *Arbeit und Gesundheit*, 1929, No. 12.

In accordance with the Order of 11 February 1929, by which the list of occupational diseases subject to compulsory compensation was considerably extended, " severe pneumoconiosis " (silicosis) was also included, in so far as it occurred as the result of occupational activity in the following industries:

(*a*) Establishments engaged in sandstone extraction, manipulation and manufacture.
(*b*) Metal grinding establishments.
(*c*) Pottery factories.
(*d*) Mining undertakings.

In the case of severe dust fibrosis combined with tuberculosis of the lungs, tuberculosis is regarded as pneumoconiosis (silicosis) for the purposes of compensation.

Right to compensation is therefore confined to *severe* pneumoconiosis. As " severe " are considered, according to the German legal interpretation, in general injuries and diseases which involve a reduction of the earning capacity of the patient by at least 50 per cent. The right to compensation has a fairly extensive retrospective effect. Injuries are taken into consideration when the disease has obviously been caused as the result of occupational activity subsequent to the date 31 December 1919 in one of the industries mentioned.

The insurance is effected as in the case of the German accident insurance, through employers' co-operative societies (*Berufsgenossenschaften*), that is, special bodies founded with a view to execution of the provisions in regard to accident insurance, and protection against accident, which collect the funds necessary for their purpose from the employers in the branch of industry concerned. These societies grant, in accordance with the legal prescriptions, on the occurrence of " severe pneumoconiosis ", benefit, the amount of which is dependent upon the degree of earning capacity; they further accord benefit to the next of kin when the occupational disease has been the real cause of death.

The societies are further in a position to grant " transitional allowances " independent of the extent of the occupational loss of earning capacity when continuation of the former occupational activity is to be feared as an agent in aggravating the disease. This " transitional allowance " is intended to enable the patient to enter another occupation which does not expose him to risk.

Tuberculosis of the lungs combined with severe pneumoconiosis is regarded from the point of view of compensation as pneumoconiosis itself.

The occupational disease is subject to compulsory compensation, and also subject to compulsory notification. Notification is obligatory for the employer as well as for the doctor in charge of the case. Notification has to be made at the *insurance office*, which proceeds to thorough examination by a doctor appointed for the purpose —" geeigneter Arzt ". The society decides as to the proposed payment of benefit. Appeal to the Reich Insurance Office against their decision is possible.

In future, the institution of protective measures against silicosis in the industries affected will also come within the competence of the societies.

Prophylaxis in regard to Diseases from Dust

According to Thiele and Saupe, in the Elbe sandstone district it is the practice to wet the stone frequently, in order to reduce the amount of dust produced. Many attempts have been unsuccessfully made in regard to the wearing of respiratory masks. The workers always felt themselves unduly hindered in their work by these.

In the grinding industries, the use of ventilators in the workrooms, and of dust exhaust apparatus at the working posts has been compulsory for several decades. Processes which cause considerable dust production, such as the splitting of grindstones, have to be deferred to the close of the working shift. Teleky demands, further, that as far as possible sandstone should be replaced by artificial grindstone, and that effective dust exhaust devices should be installed, together with the separation of polishing and grinding operations.

In the china industry, also, the provision of exhaust dust apparatus, and means of maintaining the workrooms in a state of cleanliness are required. The hygienic conditions have been greatly improved during the last decades, and further improvement may be expected by the erection of partition walls to shut off very dusty processes from other departments, and by the covering-in of edge mills and similar devices in dust-tight compartments. Koelsch, further, demands thick, smooth flooring, cleaned daily by wet process, daily cleaning of the working post and tools, special working clothes, and adequate washing facilities.

In mining, many efforts have been made to prevent the production of dust and to further its removal. Many rockdrillers tie wet sponges in front of their noses, others wear respiratory masks of various patterns; most workers, however, are opposed to such measures, since they are apt to hinder work. The " duster " who sprinkles stone dusts as a protective measure against coal dust explosions, regularly wears a protective mask. Continuous sprinkling with water of drill holes is very much practised, but the contact with material which becomes wet during this process, as well as wetting of the workers' clothes, has been found extremely trying. Dry exhaust removal of dust from drill holes, on the principle of the vacuum cleaner, has likewise been applied in many places.

A prize essay recently issued on the subject of measures of protection against dust contains many new proposals, the efficacy of which time alone can prove.

In many dusty trades, the wearing of helmets with a provision of fresh air has become an established custom, as, for instance, in sand-blasting.

Where convenient, as, for instance, in the case of ball grinders, an effective protection from dust is provided by enclosing the apparatus in a dust-tight cover.

There must be emphatically demanded thorough medical examination before entry into the occupation of rockdrilling, combined with the rejection of unfit applicants, and likewise periodical radiological examination.

Of great importance for the protection against many severe forms of pneumoconiosis, is the campaign waged against tuberculosis. All individuals manifestly tubercular must be kept away from work in trades involving exposure to quartz dust. The well-organised campaign against tuberculosis engaged in for several decades past, has succeeded in bringing about a reduction in the tuberculosis mortality and morbidity rates, but during the war and post-war periods these figures again increased very considerably. In recent years there has occurred a fresh reduction as compared with the pre-war figures, and it is hoped that a further fall in the tuberculosis rate may exert a favourable influence on the campaign against the severer forms of pneumoconiosis.

The brilliant success encountered in connection with the application of well-organised measures for dust reduction in South Africa leads to the hope that in Germany also the campaign against pneumoconiosis will be crowned with success.

II. — TYPES OF DUST AND SILICOTIC LUNGS: COMPARATIVE STATISTICAL AND CLINICAL-RÖNTGENOLOGICAL RESEARCHES IN BAVARIA

BY PROFESSOR KOELSCH, MUNICH, IN COLLABORATION WITH
DR. KAESTLE, MEDICAL OFFICER OF RÖNTGENOLOGY IN MUNICH

According to the theory of pneumonoconiosis founded by Zenker, Professor of Pathology in the Bavarian University of Erlangen, in the year 1865, all changes of the pulmonary tissue caused by different kinds of dust were up to the beginning of the present century considered as fairly similar, though chalicosis (lung changes due to stone dust) took a specially predominant place in regard to its pathological and clinical effects.

The notions of the action of the various types of dust were at that time standardised in an essentially morphological manner, it being assumed that it was particularly the pointed and sharp-edged dust particles which caused mechanical wounds of the pulmonary tissue and thereby in combination with dust deposits set up injuries. Only with the observations of the last decades, and in particular the thorough investigations effected in the last fifteen years have the former theories been fundamentally altered. To-day it is recognised that the varied types of dust must be judged in a fundamentally different manner, that in this connection the decisive factor in regard to effect is not so much the morphological-physical activity of the various types of dust, but rather the content of free crystallised silicic acid (quartz). Where it is a question of mineral dust, where dust with a mineral, metallic, vegetable or similar content is raised, the deciding factor in settling the question from the point of view of industrial medicine is the relative presence of free silicic acid; it need hardly be added that the amount of dust, the duration of exposure to it and other external factors also play their part.

Wherein does the specific effect of silicic acid consist? In addition to morphological properties such as hardness, sharp glass-like fracture, there come also into consideration certain chemical-necroctic fibro-plastic effects, interference with the cleansing mechanism of the lung in regard to dust removal, disturbance of the bactericidal power of the blood and other factors; these problems still await solution at the present time.

It is, besides, now known that the various forms of pneumonoconiosis manifest fundamental differences from the pathological-anatomical and clinical points of view—that in reality it is only injuries caused by dust with a silicic acid content, the so-called " silicosis ", which are of practical importance. Finally, it is necessary to distinguish between " dusty lungs " and pneumonoconiosis, for not every " dusty lung " as regards silicosis implies disease in the clinical sense, involving a right to compensation; only in the case of average and severe forms is it possible to speak of pneumonoconiosis. The same is true of uncomplicated silicosis; yet in the latter case certain complications may be brought about especially through accompanying tuberculosis (silico-tuberculosis, tuberculo-silicosis) or through secondary disturbances of the circulation; such complications may under certain circumstances, even in cases where röntgenological examination reveals but slight symptoms, lead to the belief that severe illness is in question. The present-day view in regard to the problem is somewhat as described above.

The author had already commenced some years ago to prove these views statistically and clinically by large-scale investigations. In the last few years over *1,200 workers in various branches of industry involving exposure to mineral dust* were clinically and röntgenologically examined with the collaboration of the röntgenologist Dr. Kaestle: for the majority of this group of workers available history in regard to morbidity and mortality from diseases of the respiratory passages was also taken into statistical consideration. The data provided by these investigations, will be given in a comprehensive manner in the following part of this Paper, and dealt with, with the exception of granite, in order of the specific danger attaching to the dust as regards pneumonoconiosis, beginning with the occupations known to be the most dangerous.

(1) The foremost place is occupied by *sandstone workers.*

Our investigations covered workers from the variegated sandstone district on the lower Main (Miltenberg, Marktheidenfeld) and from the white sandstone district on the middle Main (Eltmann, Zeil). The material worked consisted of quartz granules of varying size baked into a conglomerate with argillaceous cement. The total silica content amounts to 80-85 per cent.; it consists almost entirely (90-100 per cent.) of free silicic acid. The microscopic picture of the *fine dust* reveals considerable quantities of quartz crystals. Statistical analysis of the data furnished by the General Local Sickness Fund at Marktheidenfeld revealed the fact that sandstone workers there (calculated on the full working complement) showed on a four-year average, in respect of pulmonary tuberculosis, a morbidity rate about five times that for the remaining insured male population of the same age. The rate for other diseases of the respiratory system was likewise higher (10.50 as against 7.71), while the rates for all other disease forms including accidents occurring amongst sandstone workers were lower (the total being 59.18 as against 61.88). In the case of the General Local Sickness Fund of Miltenberg, the three-yearly average showed a considerable excess for sandstone workers for all forms of disease of the respiratory system including tuberculosis (15.8 as against 5.2). In the case of the Trade Sickness Fund of the firm Ph. Holzmann, the rate for diseases of the respiratory tract, including tuberculosis, amounted for the three-yearly average affecting sandstone workers, to 1.25 per cent., while for the remainder of the insured workers it was 0.90 per cent.

The *death register* showed the following results (three-yearly average):

District	General mortality		Tuberculosis, lung diseases	
	Stone-workers	Other males	Stone-workers	Other males
	Per cent.	Per cent.	Per cent.	Per cent.
Marktheidenfeld	5.60	1.64	5.32	0.2
Miltenberg	3.83	1.64	3.11	0.2

About 173 workers in all were covered by the *clinical röntgenological examination.* Whilst deposits of stone dust were only found to a small extent, 1 per cent. in the case of workers with a five years' record of work, the amounts found in the case of workers old in the trade grows to such an extent that workers with a twenty to forty years' record showed up to 76 per cent. affected by severe injuries due to dust. Taken all in all there was found in the case of 36 per cent. of the workers indisputably positive lung changes as indicating silicosis, of which five were probably combined with tuberculosis.

The Röntgen ray picture showed here quite typical changes; in pronounced cases both lungs were found to be fairly evenly infiltrated with numerous isolated foci, characterised by strikingly profound shadows and sharp borders of the isolated foci; the foci with fine mottling gave the appearance of small shot (bird shot). The site favoured was the middle and lower region of the lungs. There were also found pictures showing broadened flakelike foci distributed fairly symmetrically over both lungs; these massive broadened foci were likewise characterised by the depth of their shadows. To these were added massive hilus nodules with sharply outlined arborification, and further, not uncommonly pleuritic changes, adhesions, etc. The general impression is one of a severe mass of dust infiltration of the pulmonary tissues.

(2) In the neighbourhood of Neuburg on the Danube, the so-called *siliceous chalk* is extracted, which contains about 86-97 per cent. of silicic acid mostly in a free state. Thirty-nine of the workers engaged there were examined clinically and radiologically; the majority had, it is true, been working in the trade for under ten years (frequent change of occupation !). Most of these were found to be relatively healthy; on the other hand, eight showed clear signs of silicosis, mostly in the form of mixed large nodular and fine mottled foci; the shadows were somewhat less profound; between numerous soft shadow areas with relatively sharp outlines lay solitary thick foci with profound shadows resembling those typical of pure sandstone pneumonoconiosis.

(3) Less on account of its place in the order of danger, but rather on account of the type of Röntgen picture connected with it, an account of the *granite stone industry* may be added here. Granite dust contains between 61 and 82 per cent. of silicates; the content in free crystalline silicic acid is said to amount to about 25-30 per cent. The physical combination of the quartz crystals is probably a very firm one in this case. Statistical analysis of the data of the General Local Sickness Fund for the Passau district, counting upwards of 1,600 granite workers (full working complement) amongst its members, showed more favourable figures relative to respiratory diseases including tuberculosis of the lungs in comparison with similar age-groups amongst the remaining male members insured. Likewise the mortality rate for granite workers as against that for the general male population in the same district was in nowise excessive. It was even, on the other hand, more favourable: mortality rate from all diseases (three-yearly

average) 0.56: 2.11. The mortality rate for tuberculosis was 0.14: 0.16 per cent. The anamnestic and clinical investigation next covered 200 granite workers of the lower Bavarian forest. It revealed in general more favourable conditions than had been expected. A thorough clinical and röntgenological examination of a further 93 granite workers from the Fichtelgebirge was effected later, almost 82 per cent. of the workers in question having been engaged in the occupation for upwards of ten years (up to fifty years); 64 of these showed no symptoms of any kind. Clinical findings in respect of subjective complaints were present in the case of 20 workers, yet the röntgenological examination showed in all these cases fairly normal conditions.

Clear pneumonoconiotic changes were only established in the case of 5 workers in all (out of 93)—that is, hardly 5 per cent. of the workers in question having a record of work as granite cutters of between twenty-five and thirty years. The pneumonoconiosis of the granite workers examined by us is characterised by moıe or less numerous, fairly thick, small foci of the size of those produced by sandstone pneumonoconiosis, by arborification starting from more or less distinct enlarged and thickened hilar markings, especially in the right towards the basal and also the other regions of the lung. The speckled shadows are localised as in other types of silicosis, that is to say in the middle and infraclavicular lateral regions of the lungs. In the cases examined by us the small foci did not in general attain the thickness of the finely mottled forms found amongst victims of sandstone pneumonoconiosis; solitary nodules approached this thickness. The smaller content of crystalline silicic acid in firm combination with other harmless accompanying minerals may indeed be considered to be the chief reason for the diminished biological effect of this mineral dust in general on the lungs.

(4) Special interest has been taken in *porcelain workers*, the dust risk to which they are exposed having for long been disputed. The possibility of contamination of the atmosphere by dust in the porcelain industry is freely admitted. I have determined the presence at various working posts of concentrations of between 22 and 205 and over milligrams of dust per cubic metre of air. The porcelain contains 42-66 per cent. of clay (aluminium silicate), 17-37 per cent. feldspar (potassium aluminium silicate), 12-30 per cent. quartz (free silicic acid). In the glaze there is about 30 per cent. of quartz, 30 per cent. feldspar, 26 per cent. calcspar,

10 per cent. porcelain fragments and smaller quantities of other mineral by-products. The dust is very fine and very volatile, though it is necessary also to take into consideration the fact that owing to the hardening process (vitrifying) a part of the free silicic acid in the quartz enters into combination with the potassium and aluminium.

I had long ago undertaken comprehensive statistical research in regard to the liability of porcelain workers to diseases of the respiratory passages or tuberculosis, the results of which, similar to those achieved by earlier authors, confirmed the high morbidity and mortality rates of these workers from diseases of the respiratory passages, including tuberculosis. As an example I established the fact that in certain typical porcelain districts of Bavaria perceptibly higher mortality rates occurred amongst porcelain workers for tuberculosis and other chronic lung diseases in comparison with members of the general population belonging to similar age-groups—in Selb and Rehau a fourfold, in Tirschenreuth, Kronach, Teuschnitz a two or two-and-a-half times increased mortality rate. Similarly the actual porcelain makers showed an increased morbidity rate for respiratory diseases—for instance, in Selb 11.22 per cent. as against 8.44 per cent. for the other workers in the same factories. Clinical examination (without röntgenological plates) revealed, in the case of about one-half of the 1,000 porcelain workers examined, changes in the lungs which must be ascribed to injury due to dust. It was possible to prove correspondence between duration of employment and changes in the lungs.

There was effected a further clinical and röntgenological examination of 500 workers. In this case it was found that about 55 per cent. of the male workers and 35 per cent. of the women workers, giving an average of about 45 per cent., showed changes of the lungs of varying degree due to dust.

Critical consideration of the data provided by these examinations lead to the following conclusions.

In the case of workers who had been engaged in the porcelain factory for a few years there was entirely lacking specific dust changes of the lower respiratory passages or where present at all these showed but slight development. In the case of *older workers* with a relatively short duration of work the changes were more plainly seen and more obstinate than in the case of *younger* workers with the same duration of employment. Here an important part is played by the vitality of the entire constitution and of the respiratory system as a defence against injury, and in regard to the self-cleansing mechanism for removal of the dust which has penetrated into the respiratory passages. With advancing working experience the symptoms of dust infiltration of the respiratory organs increase from the subjective, clinical and röntgenological point of view.

The first signs of dust in the lungs of porcelain workers are revealed röntgenologically by numerous shadow patches of almost similar size distributed over the two central parts of the lung being about a pin's head in size or a little over. The shadow patches are relatively soft and the borders are of average sharpness. In places there is to be seen in addition signs of chronic bronchitis and peribronchitis, especially in the infraclavicular and lower, but also in the upper and lateral parts of the lungs in the form of bands with a double contour and showing nodular swellings in their course.

Besides these changes there occur, especially after long occupational activity and with advancing age more or less widespread, broad, thickened areas in the lungs, mostly in the middle regions, reaching from about the clavicle to the upper end of the lowest third of the lung.

Dry pleuritic changes (hairlike lines in the lungs, displacement of the diaphragm, thickened reticulated areas) are often met with even in the case of incipient forms of porcelain workers' pneumonoconiosis; on the other hand, exuding pleurisies are seldom met with in cases of pure pneumonoconiosis. Secondary changes of the heart (dilatation, hypertrophy) are by no means rare in such cases of severe pneumonoconiosis affecting porcelain workers. Obstructed blood vessels and obstruction in the parenchyma and interstitial spaces complicate the Röntgen picture turning it in its entirety or in part into an inextricable chaos.

Inflammation of the lungs, bacterial infection especially accompanied by tuberculosis to which porcelain workers are beyond doubt more liable as compared with the general population, may at any time lead to premature death in the case of these porcelain workers, whose lungs and circulatory organs are already impaired. In some cases, tuberculosis was found, also cavernous phthisis of tubercular origin affecting porcelain workers who had been employed up to a late age; in such cases it is indeed possible to speak of the retarded effect of indurated lung changes. No accurate knowledge is available to enable us to ascertain how many porcelain workers—men and women even in their *early* years in the incipient stages of porcelain pneumonoconiosis, that is at the irritation stage, are eliminated on account of pulmonary tuberculosis infection and take up other employment or meet with premature death.

(5) *Chamotte industry.* — By "chamotte" is meant fired clay with a high melting point which is ground down, mixed with ordinary clay and fired to make bricks. This mass contains about 70-75 per cent. of aluminium, about 2.5-3 per cent. of spar, about 20-26 per cent. of quartz, and the total silica content amounts to 25-30 per cent.; the free silicic acid becomes combined with the potassium and aluminium to a considerable extent in the firing process (vitrifying), so that in this way the free silica content is eventually considerably reduced: "probably free silica is hardly present any longer in the finished article". The dust is relatively large grained, heavy and less volatile.

Examination was made of 234 chamotte workers. The data provided by the investigation was so arranged that two groups were formed according to the röntgen findings: group I with negative or harmless röntgenological results, and group II with positive results. Group I comprised 184 individuals (78.63 per cent. of all examined), of whom nearly 65 per cent. had been in the industry upwards of ten years.

Group II comprised 50 people (= 21.37 per cent.), most of whom were of advanced age; 92 per cent. had been in employment for upwards of ten years. Subjective complaints predominated in regard to this group though 20 workers made no complaints. Clinical examination of the respiratory organs revealed for half this group changes from the normal condition; 15 men belonging to the group, however, showed no clinical symptoms. Röntgenologically, there was established fairly plain results of dust in the lungs, which may be summarised thus in passing. Once again there was revealed lack of correspondence between complaints, and clinical and röntgenological findings to such an extent that workers with fairly severe objective symptoms were free from complaints, or again that workers with subjective complaints showed relatively slight objective signs, and so on. *The Röntgen picture* showed chiefly, sparse, multiple, fine mottled isolated foci, distributed in various ways over the lungs with masses of thickened reticulated areas and hilum markings; the shadows were soft and in this respect occupied a place somewhat between those of porcelain and cement coniosis; they were relatively small with sharp outlines. The lungs often showed a particularly wavy appearance as if sown with small grains of grit. The broad shadow patches were distributed either uniformly over the whole lung, the basic parts being slightly less involved, or (more rarely) over the lateral parts of the lungs.

In general, it was possible in this case also to establish the fact that those with a long duration of employment showed greater injury from dust than those with a shorter record of work, that however in spite of this fact, even in the case of a record of ten to twenty years' work, the changes due to the presence of dust in the lungs only attained a moderate degree. It was not possible to observe here cases of the three stages of the disease. Almost three-quarters of the total number of workers examined having upwards of ten years of employment in the chamotte industry showed *no or only very harmless* pulmonary symptoms on röntgenological examination. In any case the results of our investigations here were by no means without value in regard to the distribution of injuries of the respiratory passages due to dust, since they served to indicate that the dust raised in the manufacture of chamotte contains little free silicic acid, but on the other hand has a rich clay content.

(6) *Shell limestone.* — Shell limestone consists for the most part as its name implies of mussel shells which are bedded in clay, also principally of carbonate of lime and clay with, as the case may be, an admixture of iron. Free silicic acid is not present, or at least only in traces.

Statistical analysis of the data provided by the General Local Sickness Fund for the Würzburg district, to which all of the more important establishments of the Bavarian shell limestone industry belong, showed, in the three-yearly average, that the shell limestone workers as opposed to the remaining male members insured, were more favourably placed both as regards general morbidity rates and morbidity rates for respiratory diseases, including pulmonary tuberculosis.

Likewise the mortality rates would appear to be by no means less favourable than those for the general male population. The first (merely anamnestic-clinical) examination covered 200 workers, of which 72 per cent. had been upwards of ten years in employment. Two-thirds of them were designated as quite healthy; in the case of one-third only slight symptoms of the respiratory passages were confirmed. Better results were afforded by the later clinical röntgenological examination of a further 124 workers most of whom had been more than ten years in employment; of these 81 had previously worked exclusively in the shell limestone industry (Group I); 14 of these showed dust deposits in the pulmonary tissue with no complaints or very slight complaints. Röntgenologically there was found in 8 of those examined large hilum glands, at times with a brighter nucleus and a thicker capsule. Four examinations revealed sparse fine mottled foci distributed over the lungs irregularly, and atypical as regards site; in 2 cases there were fine mottled foci with nodes in the hilum. The fine mottled foci were soft in shadows, not very thick and at the same time fairly plainly outlined in contrast to their surroundings.

That fine mottled foci are seldom found in the lungs of limestone workers, in spite of the dust evolved during the work, is partly explained by a certain solubility of lime dust in the respiratory passages, by its rapid elimination, and partly by the tendency of lime particles to coalesce and so to become too big to penetrate into the deeper respiratory passages. They irritate the mucous of the larger bronchial tubes and are in part reabsorbed and in part eliminated. It is seen from these investigations, that also limestone under certain circumstances may cause alteration of the lungs as indicating pneumonoconiosis if only it is allowed to exercise its effect for a sufficiently long time. Still these pictures are clearly distinguished from Röntgen pictures for instance of sandstone or porcelain workers. Group II (43 workers) had also manipulated sandstone for some time as well as shell limestone, 29 of them having handled more shell limestone and less sandstone (M workers)—14 the opposite (S workers). In the case of the M workers, 13 showed a normal condition of the lungs, 6 border symptoms and only 10 (34 per cent.) lungs with a dust deposit. Of the S workers, on the other hand, 10 (71 per cent.) showed clear changes in the lungs due to dust.

If Groups I and II be compared it is found that in manipulating pure shell limestone (Group I) the percentage figure for negative pulmonary cases is by far the predominant one and the figure for clear cases of pneumonoconiosis is considerably less, whilst under the influence of sandstone dust (Group II) these relations are reversed. It may be deduced therefrom that work amongst sandstone even when—and this is almost constantly the case amongst our people—work has only been carried on for a few years (mostly three to five or to eight) and when years and decades have already elapsed since the employment in question, always leaves traces in the pulmonary tissues, which it is true very often remain latent from a subjective or clinical point of view, but can nevertheless be "brought to light" by the Röntgen rays. Whether and to what extent the later work among shell limestone may have influenced favourably the residual effects of work among sandstone we do not dare to decide with certainty.

As far as the Röntgen picture in particular for Group II (combination of earlier work among sandstone with later employment in an atmosphere of shell limestone dust) is concerned, the following comprehensive account may be given: in this group there are found clear pictures of sandstone coniosis resembling those above described; there may be recognised in this case in the typical pictures of lungs resembling grains of small shot the one-time influence of a mineral dust with a high quartz content on the lung. There are found in part also on lung pictures with typical sandstone-coniosis foci resembling those found in shell limestone-coniosis: less profound shadows than in the case of the fine shot shadows, with fairly sharper outlines; also enlargement of the hilum glands and thickened areas are found. It is true that under the influence of subsequent work in an atmosphere of shell limestone the traces and effects of earlier work on sandstone had not been—or at least had not been constantly—eliminated but have rather persisted.

(7) *Cement.* — In cement dust (lime-aluminium-silicate) there is found 19-26 per cent. of silicic acid, though in general combined with calcium oxide and alumina in a non-soluble form.

If the following morbidity rates are made to refer to 100 workers per annum they provide percentages as follows: diseases of the upper respiratory passages, 6.6; diseases of the lungs (inflammation, tuberculosis, pleurisy), 4.2; 2.4 per cent. were treated annually for pulmonary tuberculosis (2.6 per cent. of the cases of sickness); in none of the cases referred to was an abnormal duration of illness established; most of the cases of sickness recovered after from three to four weeks. Of the cases of bronchial catarrh none lasted longer than thirty days; cases of inflammation of the lungs with a duration of from three to six weeks correspond to the clinical type; cases of delayed resolution (over fifty days) were not observed to any extent. The mortality rate for cement factory workers showed no difference from that for the local population at the same ages, but rather remained considerably under the average for the district; the tuberculosis mortality rate in particular was within ten years under the average for the whole Bavarian population.

The anamnestic-clinical examination of 600 cement factory workers showed no unfavourable results; in about 10 per cent. bronchitis, etc., was present; in about 15 per cent. of the cases changes in the respiratory murmur as indicating a dust deposit were observed.

Recently a further 93 workers were thoroughly examined clinically and röntgenologically, 85 per cent. of whom had been in employment for upwards of ten years; 79 of these showed negative röntgenological results, though a few suffered from slight complaints; 4 further cases showed relatively benign tubercular processes without a considerable rôle being played by the presence of dust; 4 further cases showed border signs, 6 clear signs of pneumonoconiosis (5 of these with over ten years of occupational activity). There was only *one* picture of the pulmonary form of pneumonoconiosis. The 5 remaining cases belonged to the hilar form, that is to say, there was found enlarged and thickened hilum markings —mostly with small thickened deposits—and thickened arborification of the hilum in parts of the lungs only, or all over. Only 2 of the cases observed by us showed these phenomena in a pronounced form, the remainder in a slight form. Pure cement-coniosis as revealed by our investigations was slight in extent and benign; it was clearly distinguished from sandstone workers' silicosis; the foci shadows were softer, less profound, the characteristics of the " fine shot lung " are lacking in cement workers' coniosis. Thickened foci are also found here in isolated areas.

Now how is this relatively favourable effect of cement dust to be explained ? The high limestone content has been alleged to be 66-67 per cent., of which the favourable influence on tubercular processes is well known. Likewise the solubility of the cement in water containing carbonic acid is of importance as regards the self-cleansing mechanism of the body. Perhaps its capacity for swelling also plays a part, and thereby facilitates the resorptive influence of the carbonic acid (Schott and others). Most important of all however would appear to be the fact that cement dust—in contrast to dust with a high percentage of pure silicic acid—does not remain free in the tissues but is greedily absorbed by the dust cells and removed. There is lacking here—just as in the case of lime and gypsum dust—the capacity for forming typical fibroses.

(8) Finally mention should also be made of workers engaged in handling basalt and melaphyr chiefly in *macadam* factories. The total silicic acid content is here said to amount to about 50

per cent.; free (crystalline) silicic acid is however not present. The statistical clinical examination covered 200 workers, 70 per cent. of whom had a ten years' record of occupational activity. Since the anamnesis as well as the clinical examination provided no striking results, and further the analysis of the sickness returns revealed no increased disease liability for this category of workers as compared with similar groups in the same district, röntgenological examination was dispensed with.

The outcome of the examination of groups of workers exposed to mineral dust of varying composition may be summarised as follows:

The *statistical* morbidity and mortality returns, as well as in particular the clinical-röntgenological examinations, show clearly that the fundamental principle is as follows: the greater the quantity of free silicic acid in the dust the more dangerous it is for the lungs—thus it is also found in reality that in the case of occupational groups brought into contact with substances rich in free silicic acid (sandstone, so-called siliceous chalk, to some extent also porcelain) there exist increased morbidity and mortality rates from chronic lung diseases (silicosis, silico-tuberculosis); on the other hand statistical returns are the more reassuring the less free silicic acid is present in the dust in question (workers handling cement, clay, chalk, etc.). Similar results and, in truth, still more sharply emphasised, are provided by the Röntgen picture. Here we find in accordance with the composition fairly characteristic pictures relative to the dissemination, form, thickness, outline of the shadow foci: on the one hand with the presence in abundance of free silicic acid either massed broad foci with profound shadows or more frequently, multiple, fine mottled or nodular foci with sharp outlines and striking depth of shadow of the isolated foci (lungs resembling fine shot). On the other hand the lower the percentage of free silicic acid in the dust the more the argillaceous and calcareous elements predominate the softer, the less sharp edged will be the outlines and the less profound the shadows—whether it is a question of isolated foci or conglomerated shadows. A trained research worker will in this way be able to deduct from a good Röntgen plate the relative content of the dust in question in free silicic acid, or the amount of clay or lime elements present, with a fair degree of certainty.

It is not going too far to say that the *röntgenologically demonstrable property of the biological reaction of the respiratory organs towards inhaled dust* is a good test of the content of the dust in free silicic acid. Where doubt exists as to the content of inhaled dust in free silicic acid on the basis of analyses, the Röntgen picture can furnish in *typical cases* an important indication as to the chemical activity of the type of dust in question, and its content in fine SiO_2, whether the latter has been contained from the outset in the dusty product manipulated, or has been liberated during the mechanical processes of manufacture.

We are of course quite aware that in addition to the silicate content many other factors must be taken into consideration in regard to the development and type of symptoms of the pneumonoconiosis: for instance, duration of work, working posture, and especially the constitutional factor, on which later depend to a high degree the rapidity of development of the silicosis, the self-cleansing mechanism of the lungs, the distribution of the dust deposit and of fibrosis in the pulmonary tissue and so on. Nevertheless we desire to insist with all possible emphasis on the decisive part played by free silica in the development of silicosis. This knowledge appears to us to be of special import, particularly in regard to measures of prophylaxis to be adopted by the practising factory surgeon in isolated establishments, and also for procedure in regard to the handling of the pneumonoconiosis problem from the legal aspect in regard to compensation.

BIBLIOGRAPHY

KOELSCH, F. „ Staub u. Beruf." *Handwörterbuch f. soz. Hyg.* of GROTJAHN-KAUP. Leipzig, F. C. W. Vogel, 1912.

—— " Zur Staubfrage. " *Jahreskurse f. ärztl. Fortbildg.*, 1920, No. 9.

—— " Ueber die Lungenerkrankungen der Steinhauer. " *Ztrbl. f. Gewerbehyg.*, 1915, Nos. 11 and 12.

—— " Die Staubfrage in der Porzellanindustrie. " *Sprechsaal*, 1920, Nos. 15-16. Coburg.

—— *Porzellanindustrie u. Tuberkulose. Gewerbehyg. Untersuchungen.* Habilitationsschrift. Leipzig and Würzburg, C. Kabitzsch, 1919. (Reprinted from *Beiträge z. Klinik der Tuberkulose*, Vol. 42.)

—— " Zur Frage der Staubeinwirkung auf die Lungen der Porzellanarbeiter. " *Ztschr. f. Tub.*, 1923, Vol. 39, No. 2.

—— " Arbeit u. Tuberkulose. " *Arch. f. soz. Hyg.*, 1910, Vol. 6, Nos. I, II and III.

—— " Tuberkulose und Arbeit. " *Ztschr. f. Tub.*, 1921, Vol. 34, No. 7.

—— " Tuberkulose und Beruf. " *Handwörterbuch d. soz. Hyg.* of GROTJAHN-KAUP.

Koelcsh, F " Berufskrankheiten bei Porzellanarbeitern." *Ztrbl. f. Gewerbehyg.*, 1920, No. 3.

—— " Gesundheitliche Erhebungen in bayer. Zementfabriken. " *Jahresber. d. bayer. Gewerbeaufsichtsbeamten*, 1911, and in *Ztrbl. f. Gewerbehyg.*, 1913, No. 10.

—— " Lungenerkrankungen b. d. Arbeitern der Neuburger Kieselkreide-Werke. " *Jahresber. d. bayer. Gewerbeaufsichtsbeamten*, 1921.

—— *Untersuchungen über die Staubgefährdung in den Chamottefabriken.* (To appear in the *Reichsarbeitsblatt.*)

—— " Keramische Industrie." *Handwörterbuch. d. soz. Hyg.* of Grotjahn-Kaup. Leipzig, F. C. W. Vogel, 1912.

—— and K. Kaestle. " Arbeitsmedizinische Untersuchungen über die Wirkungen verschiedener Staubarten. " *Reichsarbeitsblatt*, 1929, No. 26. Supplement (52 pages, 15 X-ray plates).

Kaestle, K. " Ueber die Pneumonokoniose der Sandstein-, Kieselkreide-, Porzellan-, Granit-, Zement- u. Muschelkalkarbeiter. " Lecture printed in: *Die gewerblichen Staublungenerkrankungen*, Supplement 15 of the *Ztrbl. f. Gewerbehyg.* Berlin, J. Springer, 1929.

—— " Ueber Porzellanlunge: Vortrag b. d. Tagung der Süd und Westdeutschen Röntgengesellschaft in München. " *Fortschritte auf dem Gebiete der Röntgenstrahlen*, Vol. XXXVII, No. 3.

—— " Ueber die Pneumonokoniose der Sandstein-, Kieselkreide-, Granit-Muschelkalk- und Zementarbeiter. " *Forschritte auf dem Gebiete der Röntgenstrahlen*, Vol. XXXVIII, No. 6