THE ÆTIOLOGY OF SILICOSIS.

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SILICOSIS is perhaps the most important of the group of lung diseases known as the pneumoconioses. All the members of this group owe their origin to the inhalation of some form of dust and the resulting alteration of the lung tissue which follows the action of the dust as a mechanical irritant. That the action of the dust is purely mechanical cannot be said to be proved, although so far as our knowledge goes at present the physical properties of a particular dust appear to determine its chief effect on the lungs and the sequence of physiological and pathological events which lead to its classification as a dangerous or as an innocuous dust.

THE EFFECTS OF SILICA DUST.

Experiments have been carried out on small animals to show the effect of various dusts on the lungs, the conditions being approximately similar in each case. In a series of such experiments made by Mr. Mavrogordato [1] the important conclusions are reached that certain dusts are taken up by cells which tend to remain in situ and form plaques, which appear early and persist, and become the site of fibrosis. To this class belong the dusts of high siliceous content. Other dusts, such as coal and shale, do not set up processes which block the lymphatics, but, on the other hand, are more readily shed.

The physiological process of elimination of the dust by the action of the bronchial secretions and cilia, and by an unimpeded lymphatic system, is of the first importance, and it follows that under any conditions which involve the inhalation of more siliceous dust than can be eliminated fibrosis is bound to result.

The reaction which initiates this process of elimination is of a catarrhal nature, and appears to be stimulated by some dusts which themselves do not tend to accumulate, such as coal and shale, and this reaction, when produced, tends to carry off the dangerous dusts with the innocuous. Certain of the experiments on animals referred to were carried out with mixed dusts, such as coal and flint, and the results, though not entirely conclusive, appeared to show that in these animals, under experimental conditions, the siliceous dust was more readily removed in the presence of coal dust than in its absence, although, on the other hand, there appeared to be a retardation of the complete clearing of coal dust from the lungs, as well as the residue of flint dust, this retardation apparently being proportional to the amount of flint dust present.

The exciting cause of silicosis is the fine dust from highly siliceous sources, which is inhaled by the workers in certain trade processes. The conditions under which the inhalation of silica dust occurs in sufficient degree to produce disease vary with the surroundings, the physical properties of the particles, and probably also to an unascertained extent, with the individual.

Silica occurs abundantly and widely distributed in nature; in some forms such as flint and chert, it is practically pure, and in ganisters, certain so-called fireclays and "pocket-clays" in quartzite pebbles, in the millstone grit, and in many sandstones, it occurs in percentages as high as 92 to 98. Many industries and trade processes are concerned in the manipulation of these raw materials, but certain of them are especially associated with the generation of fine dust and exposure of the workers to the danger of contracting silicosis.

In a series of cases of pulmonary disease investigated by the writer, the industries involved included lead mining, silica rock milling, silica brick making, scythestone making and the quarrying and dressing of building stone; in all of these, the workers are to a greater or less extent exposed to danger of inhaling silica dust in such quantity as is capable of producing definite disease of the lungs, and in many of the cases consequent invalidity or death.

In the lead mining series, which includes 16 cases, the majority worked in mines about 200 yards deep, where the rock is broken up by drilling and blasting. Although the ore occurs in the limestone, masses of chert are met with, and there is no doubt that this mineral, which is almost pure silica, is the cause of silicosis amongst these lead miners, the dust being produced in the drilling and blasting in the mines.

Dr. Greenhow [2], reporting in the middle of last century on the excessive incidence of pulmonary disease amongst the lead miners of Reeth, ascribed most of the injury to want of ventilation in the mines, but from the details of the account given by him there appears to be clear evidence of the influence of dust, which in some mines, at least, was from sandstone, and reference is made to the similarity between the conditions found in the miners and those occurring in masons and stone-hewers.

The lead miner is not unaware of this evil effect of his occupation, and he frequently seeks a respite in a change of occupation, especially favouring work in coal mines. Out of sixteen cases in the present series, eight had worked in coal mines at intervals. Whether this custom has a purely economic basis, or whether the lead miner finds an antidote in the coal dust which he inhales, is a difficult point to decide, but it is significant that Dr. Greenhow specially refers to this subject [3]. "Several lead miners who, feeling their health injured by their occupation, had either worked for a time at coal mining, or at some employment at the surface of the earth, asserted that they had by this means very much mitigated their ailments, some of them having subsequently been able to resume their original occupation": a practice which accords with the results of experiments with mixed dusts already referred to.

THE SILICA INDUSTRIES.

Silica rock milling and silica brick making represent a group of industries which are of particular interest at present owing to recent legislation, which provides that certain workers are brought within the scope of a special section of the Workmen's Compensation Act, the benefits of which accrue to such workers in the event of their developing silicosis with or without tuberculosis.

To understand the present limited application of the Workmen's Com-

pensation (Silicosis) Act, 1918, it is necessary to appreciate the fact that silica rock possesses two main properties of importance in the industries, namely, "refractoriness" and "grittiness." "In technology, the term 'refractory' usually refers to materials used in the construction of furnaces, flues, crucibles, &c., on account of their resistance to heat, when they are subjected to the cutting action of flue gases, the influence of slags, and of sudden changes in temperature" [4]. The Act at present is applied to workers concerned in the manipulation of "refractory" material containing not less than 80 per cent. silica (SiO_2) " [5], and it is not applicable to workers in any product of silica, however pure, the ultimate use of which is other than as a "refractory material." The chief refractory products containing over 80 per cent. of silica are silica bricks, ganister bricks, ganister mixture, ground ganister, pug ganister and silica cement. For the manufacture of these, the silica is obtained either as a rock, which is quarried by drilling, blasting and breaking with hammers, accompanied by the generation of dust, or as a sand, or gravel which is quarried in a more or less wet state and therefore free from dust.

For silica bricks, the raw material is conveyed to the works and broken to a convenient size by power-driven crushing machinery. This may be chiefly a wet process, but in some cases the material is kept dry and graded into three degrees of fineness before the final mixture is made and the "bond" added. When the latter method is carried out much more dust is evolved. When the crushing is completed, a "bond" is added; in silica bricks usually lime is employed, either in solution or in powder, to about 2 per cent.; for ganister bricks clay is generally used as a "bond," and the amount is varied with the grade of brick required. The mass is mixed in a mortar mill to a consistency of mortar, turned out and tempered with shovels and conveyed to the brickmakers who fill it into moulds. The "moulder" smooths the exposed side with a straight edge, sprinkles it with sawdust, sand or dust from the floor, and the "bearer-off" carries the mould containing the bricks to the drying floor, where they are turned out to dry. The use of sawdust is preferable to sand or dust, which inevitably foul the drying floor and produce dangerous dust. When the bricks are dried, they are conveyed to the kilns, in which they are stacked and fired at a temperature of about $1,500^\circ \text{C}$. for a variable number of days. Both the dried raw brick and the fired brick are dusty and easily rubbed down owing to the small amount of bond used, so that loading and unloading the kilns is fraught with danger, especially as the work is carried on in confined places where deficient light obscures the true state of the dust-laden atmosphere. Subsequent handling of the finished bricks in transport exposes the workers to some dust, but more particularly the bricklayers who are engaged in repairing the furnaces for which the bricks are used, are subjected to a dangerous amount of dust. Ganister mixture, ground ganister, pug ganister and silica cement are prepared from ganister or silica rock with various additions of fireclay or other material yielding plasticity. The preparation of the raw material is similar to that in silica and ganister brick making.

Silica rock milling is an industry which is concerned with the crushing of high-grade silica rock or sand to a fine powder, the product being used for a variety of purposes, amongst which are the manufacture of abrasive

soaps, metal polishes, paints, chicken foods and sanitary powders, and for use in metal casting. The processes of quarrying the rock are the same as those required for silica brick making, and the dangers of dust inhalation are the same. Now, the rock, in lumps up to about half a cubic foot in size, is conveyed to kilns, in which it is stacked and calcined at a temperature of 3,000° F. This has the effect of rendering the rock more friable, and unloading the calcining kiln is fraught with great danger of dust inhalation. From the kiln the calcined rock is conveyed to the crushing machinery which is somewhat elaborate, and as the process of grinding is entirely dry, the machinery is closed in completely and is ventilated by a suction draught which tends to prevent any dust from escaping outwards into the atmosphere of the sheds. The finished product known as silica "flour" is delivered automatically into sacks which are clamped on to the delivery tube, though in some works the sacks are filled with a shovel from a heap on the floor. Ordinary grades of fineness are about 120 "mesh," while the dust yielded from the exhaust draught is about 200 "mesh," and is known as "air-flown." The silica flour is sent out in sacks which have to be new or specially close-woven to obviate danger to those handling them in transport.

In the somewhat primitive industry of scythestone making, the whole process is carried out by hand. The rock, which belongs to the "millstone grit," is cut into blocks in the quarry by the "rockmen" and sent to the "splitters" who cut each block into about a dozen pieces of suitable size and shape. They then go on to the "maker" who places each piece in a trough filled with rock dust, and fashions it into a scythestone with a chisel and mallet, causing clouds of fine dust to rise in the process. After rough chipping, the stones are passed to the "moulders" who rub them down to a comparative smoothness against a kind of red sandstone. The workers usually begin the industry early in life, as proficiency is not easily attained later. No precautions of any kind are taken against the generation or inhalation of dust in this industry, although the danger of producing lung disease is well known to the workers.

In the process of quarrying and dressing building stones the conditions under which the work is done are generally known and need not be described. The important factors are, the nature of the stone and the open or confined conditions of the work-places. Sandstones of high siliceous content in which the grains are crystalline or are cemented together by a secondary silicification are the most dangerous. Some rare sandstones and most limestones have a reputation for being innocuous, whilst granites are intermediate.

Two industries associated with the manipulation of flint are the cause of silicosis, namely, flint-knapping, which has been specially investigated by Professor E. L. Collis [6], and pottery manufacture [7].

IMPORTANT CAUSATIVE FACTORS.

In all the industries referred to, the dangerous processes are those which expose the workers to clouds of fine dust at the breathing level, the conditions being aggravated where the work is carried on in confined spaces.

The amount of dust in the atmosphere of the work-place probably has

a bearing on the amount of risk to which the worker is exposed, and estimations have been made by numerous authorities in terms of milligrams of dust per cubic metre [12]; but no method based on the estimation of ponderable solids can give the essential facts required, as the dust which does the damage to the lung tissue is only the finest particles, the weight of which is inconsiderable. Coarser particles may, however, have an aggravating effect in causing destruction of the protective vibrissæ of the nostrils and producing inflammation of the upper respiratory tract.

On examination of a section of silicotic lung, the fine particles are seen within the endothelial cells in the alveoli, in the interstitial tissue and in the fibrous tissue of the nodules, and in each case the particles are very fine, measuring on an average about 1 micron ($\frac{1}{25000}$ in.). Precisely similar particles can be found in the almost imperceptible cloud of silica dust generated in many of the processes described, and can be found also in the sputum of workers, where they may be seen within the protoplasm of the large phagocytic cells, months after the worker has left the industry. This last fact, the presence of particles in the cells of the expectoration, is important: it shows that the catarrhal reaction, begun when the dust was inhaled, is continued after the inhalation has ceased so long as unfixed particles exist in the lungs. That the tendency is for the lungs to be cleared of particles is evident from experimental and pathological observations. Speaking of the reaction to dust in coal miners' lungs, Wainwright and Nicols [8] noted that the lungs of miners who had been off work in the mines for years before their death, showed that the irritated epithelium had become normal, and the alveoli contained no dust, but the dust in the alveolar walls, septa and peribronchial tissue remained, as also did the connective tissue thickening.

It is therefore the residual particles which fail to be removed by the catarrhal reaction and expulsive processes, that produce the damage to the lung, a damage which begins when the rate of inhalation of dust exceeds that of expulsion, and continues throughout the morbid tissue changes which result.

The factors which determine the occurrence of silicosis in the individual are obscure, but that some idiosyncrasy exists appears to be clear from the fact that persons working under conditions apparently entirely similar, show widely different propensities in developing the disease.

The relation to tuberculosis is also still a matter for research. Dr. Peacock [9] stated in regard to the Cornish miner, that a predisposition to tubercle determined its development, and Dr. Greenhow expressed a similar view regarding the lead miners of Reeth [10]. It may be worthy of note that in the writer's series, of 36 deaths two cases died at the age of 21, both of whom had T.B. in the sputum and one had a definite family history of tubercle, while in the other the history was doubtful. One died at 29, who had T.B. in the sputum and a family history of tubercle. No other case in the 36 deaths is under 30. The conjunction of T.B. in the sputum and family history of tubercle occurs again in a case aged 25, who is now suffering from advanced pulmonary tuberculosis. Three other cases present the same conjunction of T.B. in the sputum and family history of tubercle, all having died at the ages respectively of 43, 48 and 50, of whom one presents a period

of invalidism of eight months, and the others two months and three months, that is, showing a definitely rapid course.

The influence of hereditary predisposition in tuberculosis with silicosis is probably similar to that found in tuberculosis alone, namely, an adverse influence on the prognosis. The effect of silicosis as a predisposing cause of pulmonary tuberculosis has frequently been referred to in the literature [11], and the high incidence of definite tuberculous phthisis amongst workers in sandstones has long been recognised. Mortality statistics, however, can be misleading, seeing that a term such as "phthisis" can be made to include so many things, or where the terminal condition scarcely indicates the primary disease.

Much may be expected from morbidity statistics in the refractories industries, compiled from careful specialised examinations, and having definitely in view the separation of the tuberculous and the non-tuberculous, and with the object of estimating the effect of particular industries in producing invalidity and death, and of observing the value of preventive measures. By this means the tubercle bacillus may be absolved from some of the blame which rightly belongs elsewhere.

Conclusions.

(1) The exciting cause of silicosis is the fine particles of silica which are inhaled and deposited in the lung tissues.

(2) The normal lung has the power of removing a large amount of the dust inhaled before it becomes fixed in the tissues.

(3) The influence of atmospheric conditions and their relation to the development of phthisis in those exposed to silica dust, is probably contributory, but the open-air industries show a high proportion of tuberculous disease.

(4) The only rational method of combating silicosis is the prevention of pollution of atmospheres by finely divided silica, by means of exhaust-draught, water-spraying, or the use of respirators.

(5) There is great need for a serious attempt at hygienic control in the more primitive of the dangerous silica industries.

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