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# Pneumoconiosis Due to Diatomaceous Earth

## CLINICAL AND X-RAY ASPECTS

REGINALD H. SMART, M. D., Clinical Professor of Medicine
University of Southern California, Los Angeles
WALTER M. ANDERSON, M. D., Plant Physician
Johns-Manville Products Corporation, Lompoc, California

UNTIL recently a reasonable doubt has been entertained that diatomaceous earth was capable of producing disabling pneumoconiosis in human workers. In 1935 Befntker[1] concluded that up to that time, serious pneumoconiosis in man due to the inhalation of kieselguhr had not been observed. Actually, three years prior Legge and Rosencrantz[2] had reported x-ray evidence of a rather high incidence (68.5%) of "pneumoconiosis due to silica" among a selected group of Mexican workers exposed to diatomaceous earth. In their paper they classified the x-ray findings under the headings of "Pneumoconiosis: very early; early; moderately advanced; and advanced," but did not define these terms or describe the x-ray appearance of the lesions seen on the chest films. The objective of the survey was to determine whether there was an increased incidence of tuberculosis in these Mexican workers, but no mention of tuberculosis found was made in the final tabulation. No statement was made concerning the incidence of disability, although, of the 118 workers examined, one was recommended for hospital care and five others for "a change of job."

The present investigation was undertaken without benefit of the films made by Legge and Rosencrantz who deserve credit for first calling attention to this problem.

We who later observed the x-rays of men working in this plant, failed to see nodular "silicosis" as designated in the title of Legge and Rosencrantz' paper. However, we did observe the linear pulmonary changes and also the coalescent lesions which will be described later in this paper. It was only upon realizing that the inhalation of diatomaceous earth and its processed products causes a different type of reaction in the lungs than does quartz, that we began to make some progress in the understanding of this disease.

In 1943 Nordmann[3] reported six autopsies on individuals employed in the kieselguhr industry in the Luneburger-Heide deposits in Germany. These men had all been engaged in dusty operations for periods varying from two to 16 years. Typical nodular silicosis was reported in each case. It is probable that the typical silicosis observed by Nordmann was due to the high quartz (30%) content of this particular deposit. On x-ray examination of a number of fullers earth workers, Middleton[4] in 1936 reported only two cases of slight fibrosis. In 1947 Martin[5] and his co-workers examined 32 workers exposed for many years to heavy concentrations of diatomite dust with only three showing mild linear changes. In 1948 Vigliani and Mottura[6] reported "several cases of advanced silicosis among workers employed in the manufacture of filter candles." In their paper the statement is made that "Gardner's opinion given in 1940 that amorphous silica is less silicosis-producing than crystalline silica had contributed largely to the widespread opinion that diatomite dust is not very dangerous to human beings." Gardner's opinion was arrived at after dusting a series of animals with crude diatomaceous earth for a considerable period of time. (At that time he reported having considerable difficulty in maintaining high concentrations of dust in the dusting chambers when the humidity was relatively high.) We wish to reiterate that these observations of Gardner have been verified by our clinical experience. We have observed men exposed only to crude diatomaceous earth (some of them underground) for long periods of time (20 to 25 years) whose chest x-rays have shown only linear changes, and who have no discernible clinical pulmonary disability.

Why then is there this wide difference of

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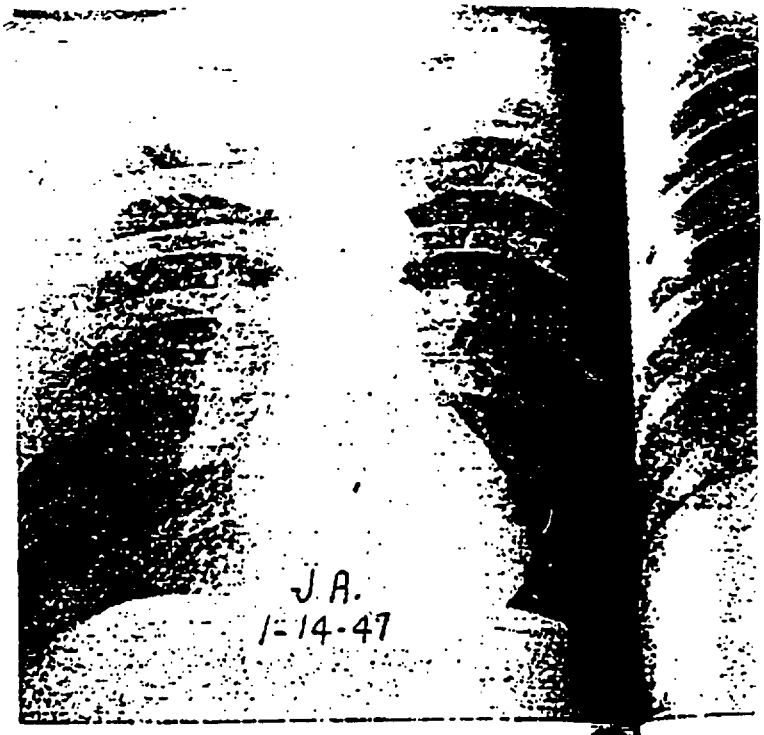
opinion concerning the toxicity of diatomite? There would seem to be at least two possible explanations for this divergence. The first might be the varying composition of natural diatomite deposits as found the world over. In addition to the possibility of contamination of diatomite earth with other minerals such as quartz, clays, etc., it should be emphasized that diatomite deposits are of two general types. Deposits found on the shores of the seas are known as marine diatomite. Material found on the floors of extinct inland lakes is classified as fresh water diatomite. There seem to be significant differences in the toxicity for humans of these two different varieties of diatomaceous earth, as will be discussed later. The other explanation may lie in the differences in the manufacturing processes of diatomaceous earth products in various parts of the world and at different times. In this industry, significant changes in manufacturing methods have occurred during the past 30 years. Until recently there has been a failure to coordinate the changes and advances made in the manufacturing processes with comprehensive industrial medical studies. These studies should include (1) the mineralogy, petrography, chemistry, x-ray diffraction analyses and particle size distribution of the products involved; (2) exhaustive engineering studies of the industrial operations, working environment and atmosphere; (3) complete medical studies of the workers themselves, including epidemiological surveys correlating work history with x-ray, clinical, and cardiorespiratory function studies of the employees, and also with pathological studies of human tissue; and finally (4), experimental studies on animals with the various diatomaceous earth products.

## Industrial Uses and Processes

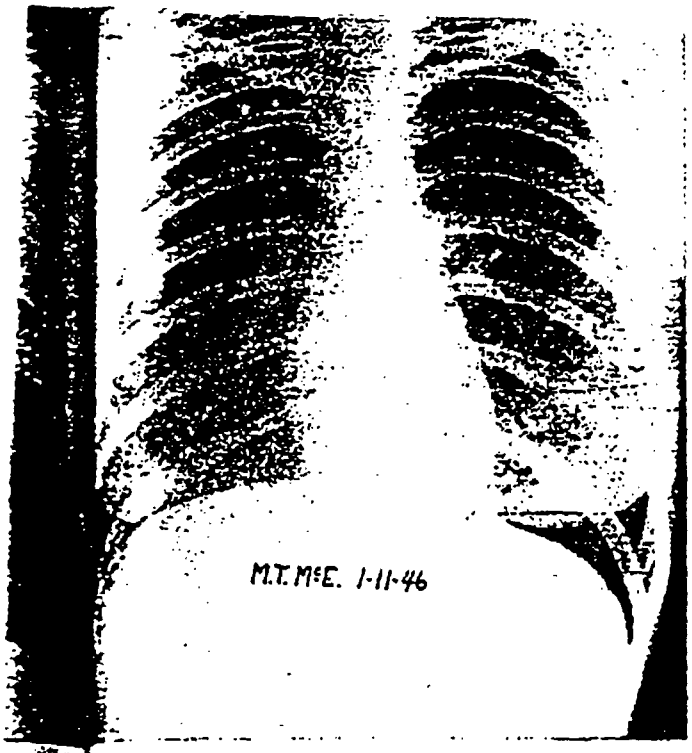
THE diatomaceous earth industry is a comparatively recent one, although diatomaceous earth has been used in various ways since the days of the Roman Empire. In 1870 Nobel invented dynamite which consisted of diatomaceous earth saturated with nitroglycerin. This stimulated the search for diatomaceous earth in Europe, where some rather impure deposits have been worked for the past 60 or 70 years. The largest and best known deposits on this continent are on the Pacific Coast, and have been producing since the turn of the century. Today diatomaceous earth has many uses, some of which are filtering aids, insulation, fillers and extenders, abrasives and polishes, and in ceramics and building materials.

In California, where the American diatomaceous earth industry is chiefly located, it was only after a clinical survey and preliminary animal studies that we began to appreciate the complexity of this problem. In the California industry a majority of workers are exposed to at least three or four qualitatively different types of silica, some of which are apparently quite toxic. Furthermore, there are differences in




Case 1.
White male, age 52 years, worked 16 years in quarries. No symptoms or physical signs. Film shows second degree linear fibrosis.

Case 2.
Mexican male, age 41 years. Worked four years as tunnel kiln helper and piling brick, and 21 years in the laboratory. X-ray unchanged since 1940 and shows third degree linear fibrosis, indefinite nodulation, and hilar enlargement. Tuberculin, coccidioidin and histoplasmin skin tests all positive. Serology for coccidioides negative. Sputa and stomach washes repeatedly negative on culture and animal inoculation. Ventilatory pulmonary function tests only slightly impaired. Patient suffered subacute bacterial endocarditis in 1950 and coronary thrombosis in 1951 from which he has made good recoveries and is now well and working.



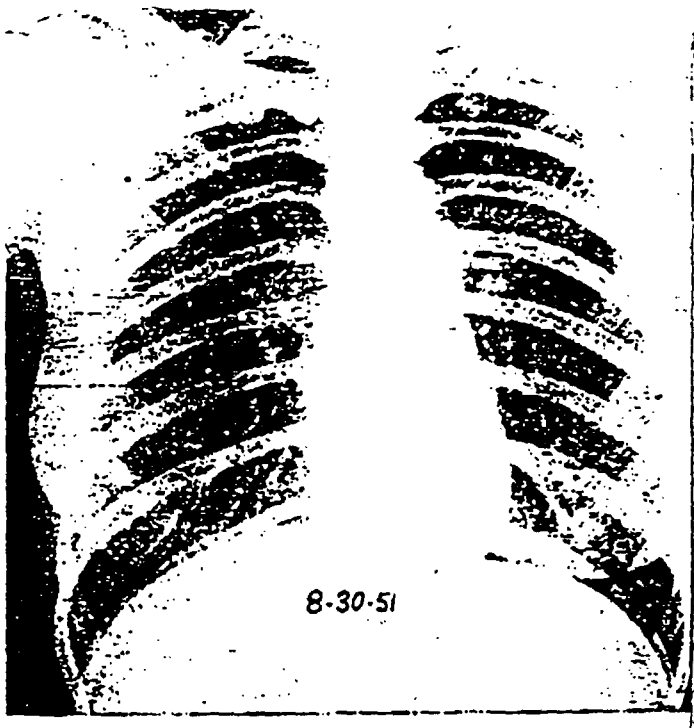




Fig. 3-A. Case 3. Fig. 3-B.

Mexican female, age 27 years. Worked one year as packer and two years as jeep driver in mill; three years as chemist in laboratory. No symptoms, delivered of healthy child in 1951. Skin tests with coccidioidin, histoplasmin and tuberculin (first and second strength P.P.D. and 10 mg. O.T.) all negative. Note in 3-b the development of bilateral mottling in mid-lung fields which simulates tuberculous infiltration.

particle sizes within the various products which may be of considerable importance in the pathogenesis of this disease. Crude diatomaceous earth and one of its products known as "natural powders" are apparently much less toxic, clinically, than some of the other forms. The rapidly progressive, coalescent lesions with resulting early disability as reported by Vigliani and Mottura, and which were also seen in California before the inauguration of adequate dust control, were in all probability due to intense exposure to one of the more toxic forms of crystalline silica. This toxicity as previously mentioned may be related not only to the type of crystalline silica, but also to particle size. A similar situation has been observed in other silica industries, i.e., bauxite fume pneumoconiosis,[7] and in men exposed to intense concentrations of very small particles of quartz such as have been reported by Sander[8] and Vorwald.[9]

Properly to understand this disease, it is necessary to have a basic understanding of the mineralogy, chemistry, and manufacturing processes. Diatomaceous earth is an amorphous form of silicon dioxide ($SiO_2$) and always exists in the form of an opal which is an amorphous hydrated silica ($SiO_2.nH_2O$) or silica and water in chemical combination. The manufacturing processes are briefly as follows:

The deposit is explored by test holes to determine the location of strata of commercially valuable diatomite, and quarry areas are laid out by use of data thus obtained. Top soil is removed and crude diatomite is taken out by power shovel and hauled to storage bins. These are actually large shafts or "glory" holes. A tunnel runs from the bottoms of the "glory" holes to the processing plant. Crude diatomite is drawn out of the holes through specially designed gates into mine cars. An electric locomotive hauls the cars through the tunnel to the processing plant.

Three types of powders are made: (1) natural, (2) calcined, and (3) flux-calcined. The natural powder is manufactured by drying, milling and air-classifying the diatomite. In the air-classifying operation impurities are removed as waste. The finished product is packed in 50-pound multiwall paper bags. The calcined product is made by passing the dried, milled, and air-classified diatomite through a rotary kiln at temperatures in the neighborhood of 1800° F. The flux-calcined product is made in the same way except that the diatomite is mixed with a flux or soda ash (sodium carbonate) before it is placed in the rotary kiln. After calcined and flux-calcined products leave the rotary kilns they are again milled, air-classified, and delivered to packer bins. Coarse and over-size particles removed in the air-classifying operation go to waste.

A number of other products are prepared by mixing diatomite with other materials in a mechanical mixer, in an area known as the mortar plant. Weighed amounts of the various ingredients are dumped into the mixer and after a definite period of time the charge is dropped into a bin below the mixer. It is then packed into multiwall paper bags. Various types of bricks containing diatomite mixed with other materials such as clays, asbestos, etc., and heated to high temperatures are also made in this area.

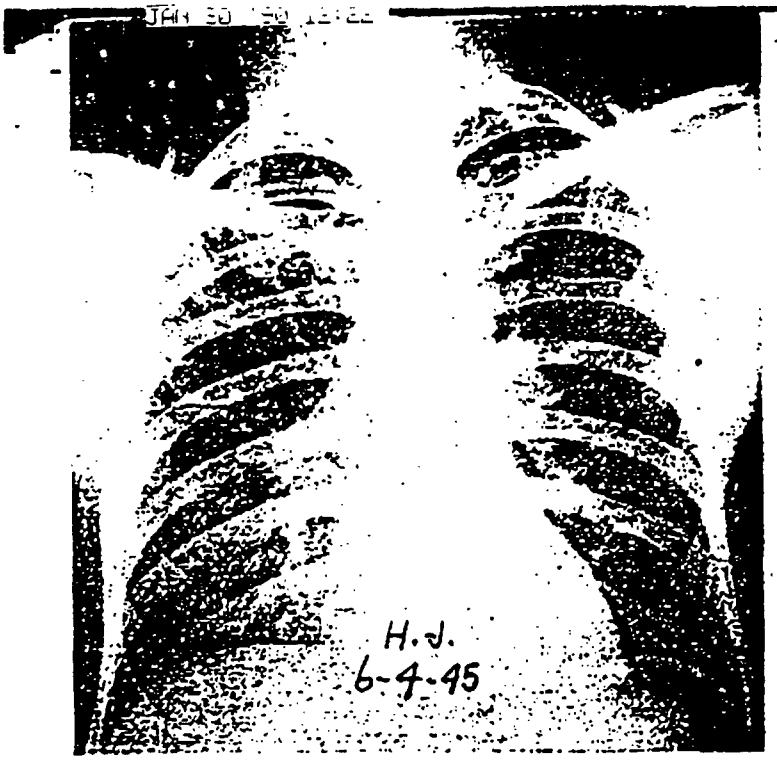



Fig. 4-A.

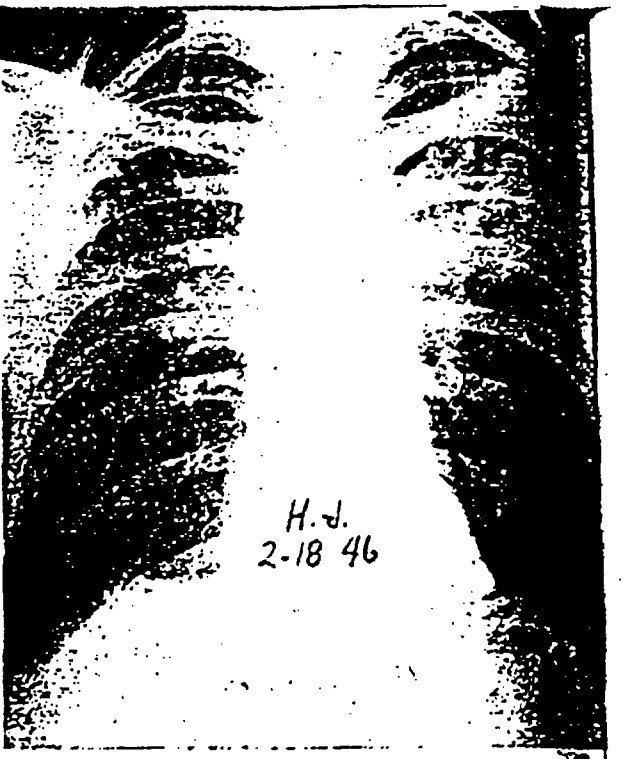


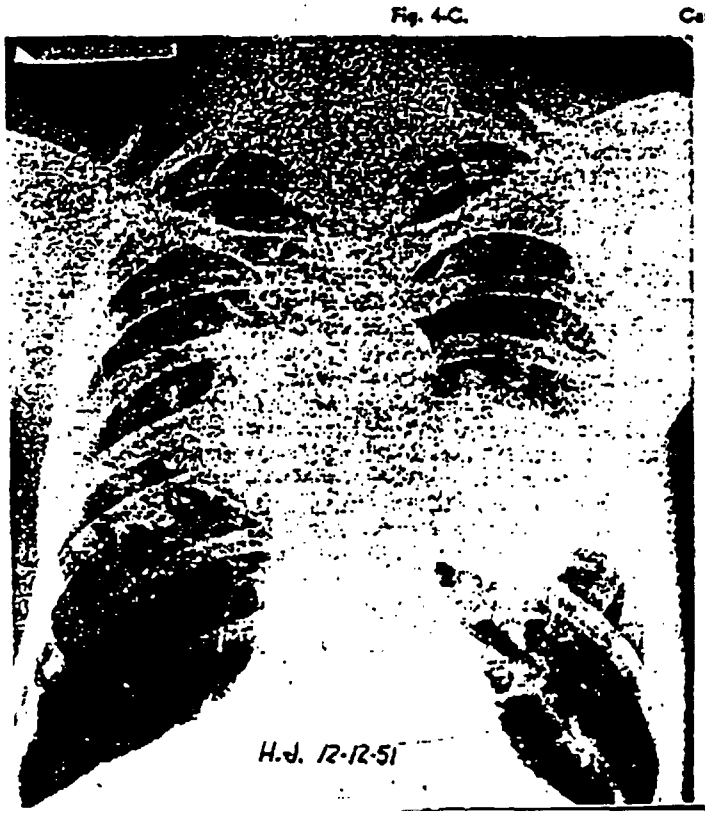

Fig. 4-B.

Case 4.

Some of these manufacturing processes result in rather important physico-chemical changes in the original crude diatomaceous earth. The production of natural powders removes the water held in physical combination or adsorbed by the porous diatoms, but it does not remove the water held in chemical combination. As a result, finished natural powders are still true opals. The simple calcination process produces a slightly different product. Heating the natural powders to 1800° F causes a physico-chemical reaction with the formation of small amounts of

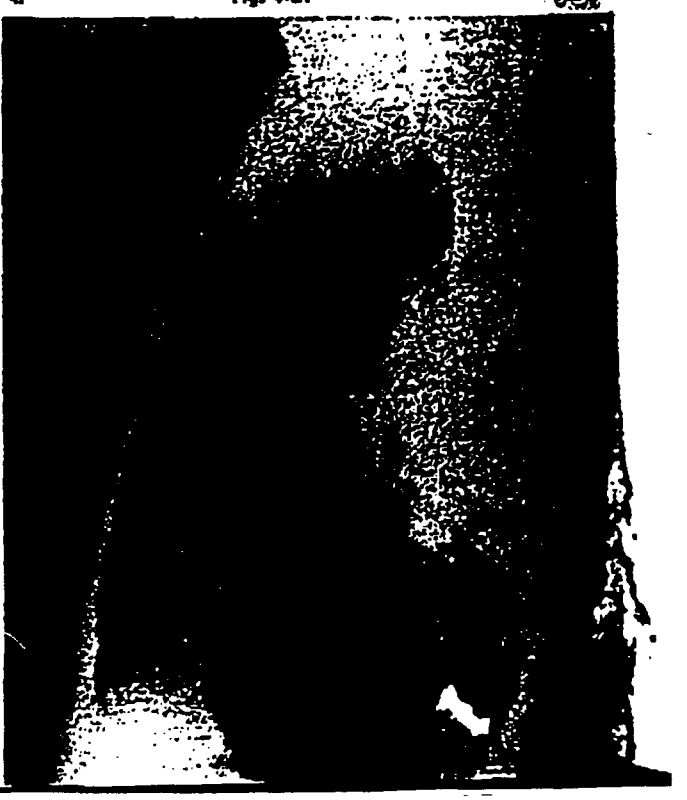
*White male, age 51 years. Worked two and a half years as a packer. Advised, and left industry at time of first film (4-a). No dyspnea then. All skin tests completely negative up to 10 mg. O.T. Many sputum specimens and stomach washes negative on culture and animal inoculation. Films 4-b and 4-c show marked progression after cessation of exposure. Severe dyspnea now. Pulmonary function tests show marked impairment. Note location of dense fibrosis in perihilar areas in Figs. 4-c and 4-d, also bullous emphysema in bases and antero-superior lung fields.*

Fig. 4-C.




Case 4.

Fig. 4-D.



a different form of silica known as cristobalite, a crystalline silica somewhat more toxic for animal tissue than quartz. Flux-calcination produces a much greater per cent of cristobalite with the formation of a trace of another form of crystalline silica, tridymite, which, according to Gardner,[10] is more toxic for tissue than is cristobalite. Some sodium silicate is also formed as a result of flux-calcination. Calcined powders contain 1% to 3% of cristobalite, whereas flux-calcined powders contain approximately 30 to 45% cristobalite and about 1% of tridymite.

Thus crude diatomaceous earth, originally amorphous in form, may be partially converted by various manufacturing processes into at least two forms of crystalline silica, and also into small amounts of sodium silicate. Inasmuch as several different products are manufactured and a number of these are of heterogeneous composition, we can expect the clinical, radiological, and pathological manifestations to be variable. The majority of the men employed in this industry have had exposures to many or all of the different products, and if pneumoconioses develop, they are apt to be of complex type.

It should be noted that great advances have been made by the manufacturers in dust control in recent years. Like all dusty trades, employee comfort requires continuous efforts to minimize dust, regardless of pathogenicity. With the advent of modern methods of dust control, exhausting and filtering, working conditions have improved greatly in this industry. Thus, many of the findings herein reported may have arisen some years ago under less favorable circumstances than now exist. Until the studies suggested above can be completed, it is impossible to relate degree of exposure to incidence of demonstrable disease.

We are presenting our clinical experience from six Pacific coast plants (three in California, two in Nevada, and one in Oregon) that are currently processing diatomaceous earth. The present clinical study makes no attempt to determine the incidence of morbidity or mortality in the workers employed in these plants. Such a study would involve the analysis of thousands of work histories, clinical records and chest x-ray films. A thorough study of such data is being undertaken as a joint project of the U.S. Public Health Service, the state Health Departments, and the three operating companies. One of us (R.H.S.) has been consultant to these manufacturers for several years and has had an opportunity to do detailed clinical and laboratory studies on approximately 100 workers. The authors have reviewed the work histories and chest films on several hundred additional employees.

In 1945 Dr. Leroy U. Gardner made a survey of the industry and since then an intensive effort has been made to secure post-mortem examinations on deceased persons who were ever employed in these plants. Twenty-two pathological examinations have been made since 1938. The pathological data are being correlated with individual work histories, chest films and clinical and laboratory studies, and will be reported in a later paper. Dr. Gardner instituted a number of animal experiments with various diatomaceous products in 1945. This work was completed and reported in 1949[11] by his successor, Dr. Vorwald, who is currently conducting additional animal experiments with these materials. It has seemed desirable to record our clinical and x-ray observations in these workers, after a brief resume of the pathological findings observed in the human cases.

## Pathology

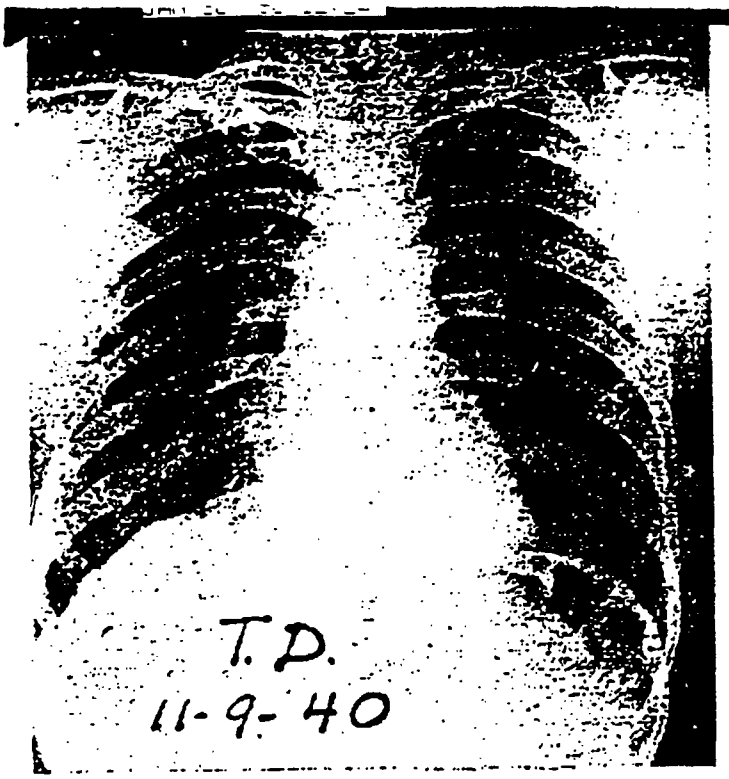
WE ARE indebted to Dr. Wm. H. Carnes, of the Department of Pathology, Stanford University School of Medicine, for the following brief summary of the pathological changes observed in the lung tissues of 20 workers* employed in this industry:

"The basic pattern of the pathological reaction to diatomaceous earth, described by Gardner in his note on the first seven cases of this series, has been present in *all* subsequent cases. This consists of a diffuse thickening of the pulmonary framework which is accentuated in the perivascular sheaths and contiguous alveolar walls. The thickening is due mainly to increased cellularity and is accompanied by more or less increase in delicate collagenous fibrils. There are conspicuous numbers of small multinuclear cells. Variable numbers of dust-laden phagocytes lie in the alveolar spaces. In *12 cases* this has been the *only* type of pulmonary alteration directly referable to dust.

"The rest of the cases have shown focal coalescence of the lesions to various extent. The coalescent lesions have varied from about 1 cm. in diameter to massive sizes, occupying the greater part of a lobe. The latter have been concentrated chiefly in the upper lobes and in the apices of the lower lobes. The coalescence is accompanied by extensive necrosis and, in the older lesions, by marked thickening and hyalinization of collagenous fibers. All four cases in which death seemed attributable to the pneumoconiosis have had extensive lesions of this character.

"The tracheobronchial lymph nodes have shown marked enlargement by massive accumulations of dust-laden phagocytes in those cases with advanced pulmonary lesions and in some of them

*Only four of these patients died directly of uncomplicated diatomaceous earth pneumoconiosis. Two other workers who died both had coalescent pulmonary lesions compatible with D.E. pneumoconiosis, and one of these also had quartz silicosis. (This was corroborated by the occupational history as well as by histologic and chemical study as mentioned by Dr. Carnes.) The other employee had carcinoma of the rectum with metastases to the lungs. Two cases were surgical specimens from pulmonary resections done for (1) chronic lung abscess and (2) actinomycosis, on patients who are still living. Other causes of death were: coronary thrombosis two; coronary insufficiency one; tuberculosis, miliary two, phthisis one; ruptured aneurysm two (luetic one, arteriosclerotic one); apoplexy one; subacute bacterial endocarditis one; carcinoma of the oesophagus one; skull fracture one.



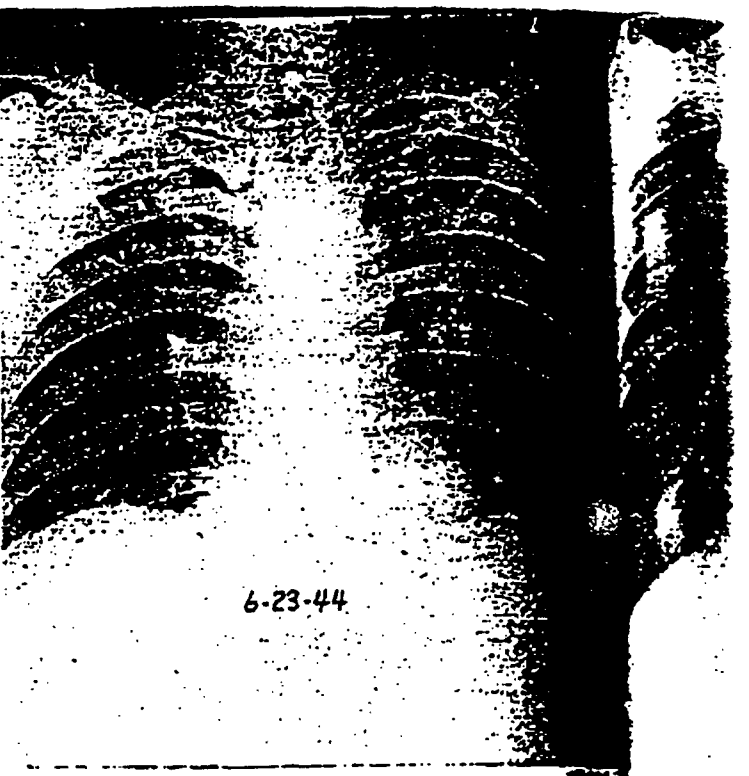




Fig. 5-A. Case 5. Fig. 5-B.

Mexican male, age 48 years. Worked six years in outside quarries and eight years in quarries and warehouse. Taken off work in 1944 because of bilateral upper lungfield infiltration thought to be tuberculosis (Fig. 5-b). Skin tests for tuberculosis positive but others negative. Many specimens sputa and stomach lavages negative on culture and animal inoculation. Employee in sanatorium one year and off work another year and a half. Minimal exposure to dust since return to work. Note development of massive coalescence and emphysema since 1944. Worker now has dyspnea and marked impairment of function tests.

focal areas of necrosis have occurred like those in the conglomerate lesions of the lungs.

"There has been a conspicuous absence of some of the cardinal features of typical silicosis, namely, the focal, discrete, hyaline nodules and the whorled pattern of the collagenous fibers. Only one case has shown these typical features of silicosis and his lung ash, unlike the others analyzed, contained a high proportion of quartz."

### Chest X-ray Manifestations

IT SHOULD be emphasized that the majority of men employed in this industry have chest x-rays which show no recognizable abnormalities. Most of the employees, whose films we will show, have been in this work for periods ranging from 15 to 25 years. There are, however, a few notable exceptions. The workers who have developed pulmonary x-ray changes can be divided roughly into two groups: (1) those having pneumoconiosis of linear type, and (2) workers with coalescent or massive lesions.

LINEAR EXAGGERATION AND GENERALIZED MOTTLING: The largest number of men whose x-rays showed abnormal chest changes were classified as having simple linear exaggeration of the finer bronchovascular pattern of the lungs. We have divided these changes into three groups according to the classification of Sampson and Gardner,[11] and have designated them as first, second, and third stage linear fibrosis or pneumoconiosis for which we use the symbols: $P_1$, $P_2$, and $P_3$. The first stage, or $P_1$, has been called "the stage of imagination" or that degree of linear exaggeration of the terminal bronchovascular markings which is just barely recognizable on the film and is often debatable. Stereoscopic films of the very best quality are necessary in order properly to evaluate these pulmonary changes. The second stage, or $P_2$, is a definite linear thickening of the finer bronchovascular structures which is seen stereoscopically to extend well out towards the periphery of the lung fields but falls short of "cross-hatching," or "reticulation," and is not at all suggestive of nodulation. The third stage, or $P_3$, has been described as verging on first degree nodulation, or the so-called $S_1$ (first stage silicosis), and some have considered these two groups as synonymous. However, in this condition there seems to be a place for the designation third degree linear pneumoconiosis ($P_3$), for, when "nodulation" occurs in this disease, the so-called nodules are seldom as discrete or well defined as is seen in classical silicosis due to quartz. In association with these "linear" changes we have also frequently seen diffuse changes best described as "cross-hatching," "reticulation" or "fine mottling." At times this simulates a fine ground-glass appearance, especially at a distance, but on closer examination is seen to have a fine lacy-like character. Gardner[12] described this type of x-ray appearance as a "diffuse mottling" and likened it to the roughened appearance of the external surface of orange peel. We prefer to designate it as a fine mottling, which may be

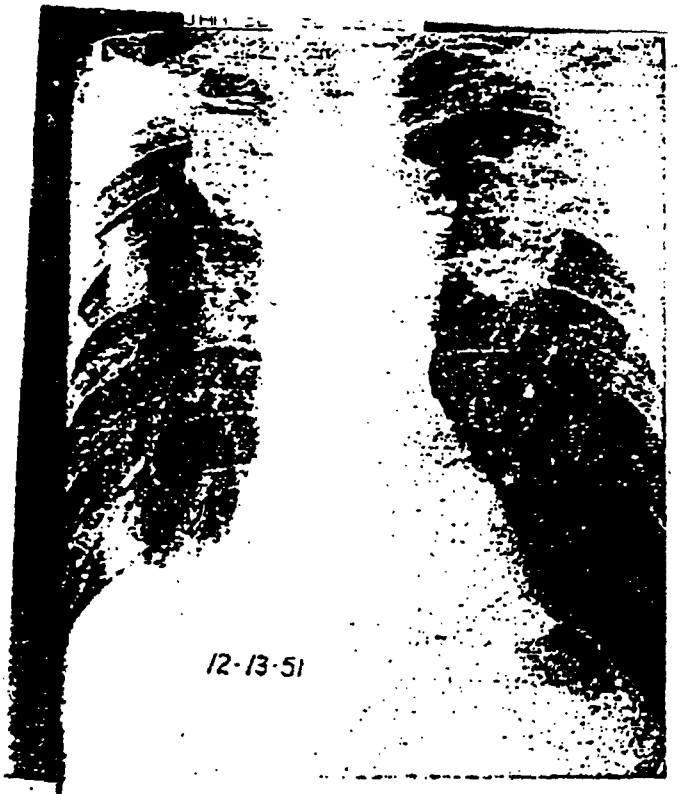



Fig. 5-C.

localized to the apices or infraclavicular zones, or may be more generalized in distribution. Amor[13] believes that reticulation "represents the next stage in the slow-progressive advancement towards definite nodulation." However, in this disease we have seldom seen reticulation or fine mottling progress to nodulation even after the lapse of many years. Furthermore, we have seen reticular fibrosis progress to the stage of coalescence without passing through a recognizable phase of nodulation. Nevertheless, we have on rare occasions seen workers whose fibrosis can be best described as nodular although the nodules have fuzzy, ill-defined borders and are less discrete than in quartz silicosis.

MASSIVE OR CONFLUENT LESIONS: As in silicosis, we not infrequently have seen massive opacities develop. These are usually preceded by diffuse, fuzzy, localized mottling, as described above, rather than by generalized nodulation. We have seen coalescence of these ill-defined, fuzzy "mottles" in both the absence and the presence of demonstrable infection. Insofar as this disease is concerned, we disagree with Pendergrass[14] when he implies that coalescence always denotes associated infection, either concomitant, or pre-existing and healed. This will be discussed later. The confluent opacities are usually limited to the infraclavicular and mid-zones of the lungs. The opacities have a tendency to be localized in the postero-superior segments of the lobes. These opaque coalescent lesions have rarely occurred after comparatively short periods of exposure (two to three years), and sometimes have been noted to become massive, and to increase rapidly and occasionally for months (as long as three years) after cessation of exposure. They have sometimes progressed to the point of tremendous contraction of the dense opacities towards the hila with the development of concomitant bullous emphysema in the extreme apices and bases of the lungs. As in Shaver's disease, spontaneous pneumothorax is not infrequent and we have seen it in 10 workers, and in four of these it was bilateral. It was either the immediate or a contributory cause of death in three of 20 patients who have died. As might be expected, extensive pleural scars and adhesions are usually seen in the instances of massive coalescent fibrosis. The diaphragms although flattened are tented, distorted, and markedly restricted in their motion. In some instances the diaphragms are drawn upward by the extreme contraction of the fibrosis and the extensive pleuritis, in others the diaphragms are depressed by the severe emphysema in the bases.

## Clinical Aspects

LINEAR LESIONS: The workers with linear fibrosis rarely have respiratory symptoms and can be compared to instances of pneumoconiosis due to so-called "inert dusts." Often the greater portion of dust exposure in the linear cases has been out of doors and to crude diatomaceous earth and natural powders. Many of the men with long exposures in the industry have chest x-rays that show only slight evidence of linear pulmonary fibrosis ($P_1$). However, we occasionally have seen men with prolonged exposure to crude diatomaceous earth and natural powders whose chest films have shown progression to a third stage ($P_3$) linear type fibrosis. Only rarely do they have respiratory symptoms. Recently have we had opportunity to do ventilatory pulmonary function studies (spirograms, timed vital capacity, and maximal breathing capacity), which will be reported in a later paper.

In the individuals having linear fibrosis we occasionally have observed localized x-ray changes that simulated super-imposed infection. Only rarely has it been possible to isolate a specific bacterium, even after using the most sensitive bacteriologic techniques available. In such cases tuberculin skin tests have usually *but not always* been positive. When infiltrative or localized mottled lesions have appeared in the chest films of men showing linear fibrosis of minor degree, ($P_1$, $P_2$), these infiltrates, which we formerly had presumed due to tuberculous infection, have often shrunk or contracted somewhat, especially if exposure to diatomite ceased.

In the few patients who have later developed frank tuberculosis, it has been extremely difficult to demonstrate tubercle bacilli before the advent of cavitation. When cavitation occurs, the response to treatment is poor and not unlike that seen in silico-tuberculosis. This is true in spite of intensive treatment with sanatorium care, chemotherapy and collapse procedures. However, infiltrates that later underwent cavitation and were proved to be due to tuberculosis,

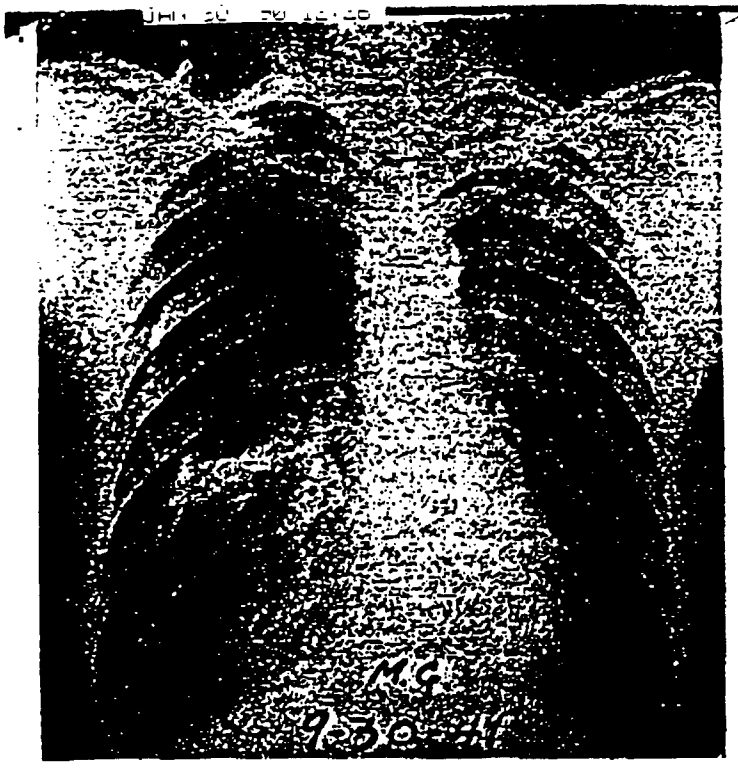



Fig. 6-A.


Fig. 6-B.

Case 6. Mexican male, age 50 years. Worked 18½ years in the stockroom and warehouse and four years in the laboratory. Tuberculin skin tests positive, others negative. Developed right spontaneous pneumothorax in 1941 (Fig. 6-a). Placed in sanatorium but sputum and gastric lavages negative to all tests. Employee left sanatorium after one year and resumed non-dusty job after two years. Infiltration increased (Fig. 6-b) and sputum became positive in 1949. Patient confined to sanatorium past three years, receiving pneumoperitoneum refills, streptomycin, PAS and Isoniazid. Sputum remains positive although cavity is smaller but not closed. Pulmonary function tests show only slight impairment.

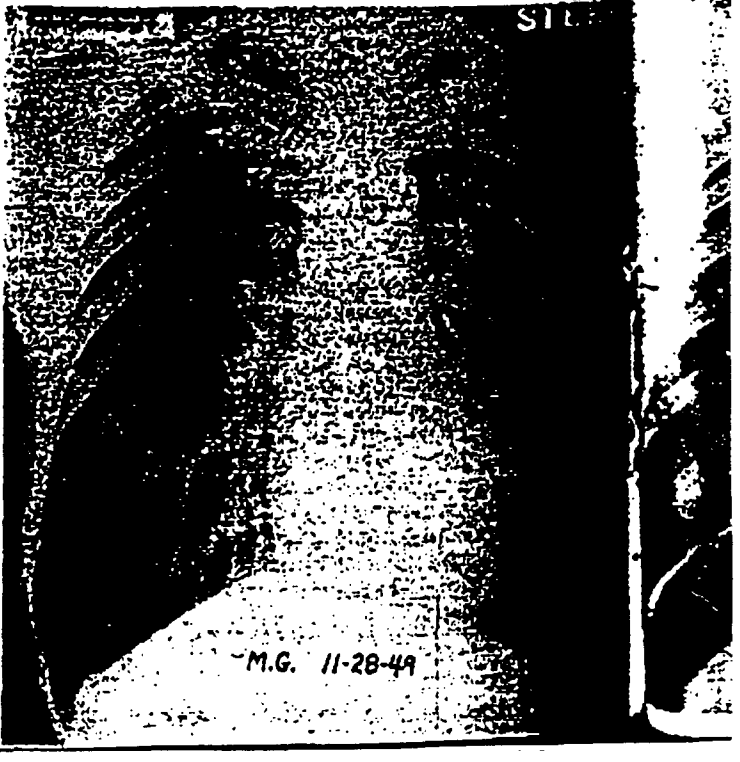



Fig. 6-C.

could not be readily distinguished in their pre-cavitary stage from uncomplicated confluent lesions. We have apparently seen a greater incidence of acute pulmonary infections such as pneumonia and pneumonitis than in the general population, which may be due to the associated emphysema. Furthermore, acute pneumonic processes do not always completely resolve and may leave extensive fibrous scars. Physical findings on chest examination were not abnormal unless infection or emphysema was present.

COALESCENT LESIONS: Of the men whose films showed only linear pulmonary fibrosis, the great majority have pursued a benign course as described above. However, we occasionally have seen individuals who developed linear pulmonary fibrosis that was progressive, and showed a great tendency towards confluence or coalescence and was followed by marked pulmonary disability and occasionally death. These men often had dyspnea, cough, dull chest pain, and sometimes cyanosis and polycythemia. If expectoration was present, it was usually scant and when combined with gastric washings has been negative for tubercle bacilli on repeated culture and animal inoculation, unless frank tuberculous cavitation was present. Dyspnea was the outstanding symptom and may develop early and be out of proportion to what is seen on the x-ray. It was the chief cause of disability. The vital capacity and maximal breathing capacity were diminished, and the breath-holding time was shortened. Spirograms showed marked prolongation of expiration. Unless manifest tuberculosis was present, fever and night sweats were absent and the blood sedimentation rate was usually consistently normal, even in the absence of polycythemia. (Polycythemia was rare and usually mild.) Al-

though infection may play a role in the pathogenesis of confluent lesions, we have seldom been able to prove it clinically or pathologically, and in many instances we feel it has been excluded both on clinical and laboratory examination, and occasionally by post-mortem studies as will be discussed later.

Persons having confluent opacities in the infraclavicular or mid-lung fields frequently have developed marked bullous emphysema particularly in the pulmonary apices and bases. This was always associated with shrinking and contraction of the coalescent lesions. The emphysema occasionally has resulted in spontaneous pneumothorax which rarely has been the immediate cause of death. Unlike the cases of simple linear fibrosis, we have often seen marked progression or increase in the confluent lesions for months and even as long as three years after dust exposure had ceased. This progression has occurred in many patients where active infection has been excluded as will be described hereinafter. In other instances the progression has appeared to halt, especially if the employee was removed from exposure. In these latter cases there often has been some apparent improvement in the dyspnea.

Physical examination revealed markedly impaired resonance over the coalescent areas which usually were located posteriorly. Bronchial breath sounds with fine rales were frequently noted over these opacities. The emphysematous areas gave the usual findings of hyper-resonance and diminished breath sounds with prolonged expiration. Although Legge and Rosencrantz reported finding a rather high incidence (72.9%) of clubbed fingers, we have never seen frank clubbing of the fingers in our patients.

Cor pulmonale has been an important complication, especially in those patients with massive coalescent disease. Of 20 workers* who died from one cause or another it was a contributory cause of death in 10. It is a prominent feature in several of the patients who are still under observation.

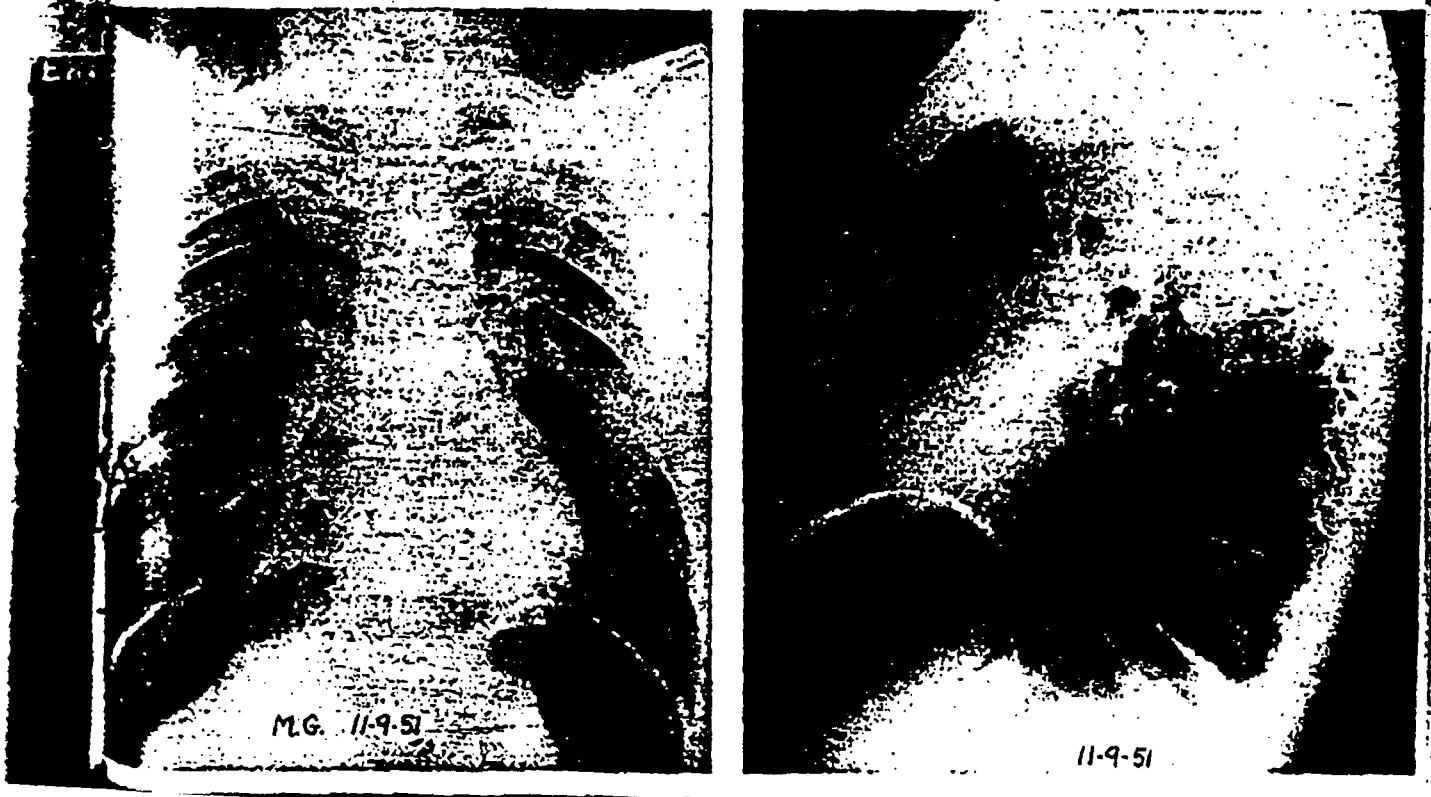
One of us (R.H.S.) has been consultant for several years to four plants processing only fresh water diatomite, and although all workers are x-rayed annually, we have never seen coalescent lesions develop among these men. The diatomite is subjected to flux-calcination in only one of these plants, but a number of men have been employed there for over 10 years. We have also observed that linear pulmonary x-ray change are found among these workers very infrequently, and then are only of minor degree ($P_1$). The explanation for this apparent lesser toxicity of fresh water diatomite is not known.

## The Role of Infection

COALESCENT LESIONS: Intra-dermal skin tests with histoplasmin, coccidioidin and tuberculin were frequently negative. In several cases having massive coalescent lesions, repeated tests to full dosage with tuberculin (P.P.D. and O.T.) were consistently negative. Repeated acid-fast cultures and animal inoculations of combined specimens of sputum and stomach washings have been negative in most of the cases of confluent disease. However, a total of nine patients have developed frank pulmonary tuberculosis, several with cavitation, and a number of these are now in sanatoria. In only one other patient were we able to demonstrate consistently any

*Necropsy was not obtained in two workers observed to have cor pulmonale during life.

Fig. 6-D. Case 6. Fig. 6-E.



other micro-organism in the sputum even after intensive study. This was a Friedlander's bacillus and was thought to be a saprophytic infection during life, and also later at post-mortem examination. Fungous cultures of the sputum have been consistently negative. Whenever coccidioidin skin tests proved positive, blood serological studies (complement fixation and precipitins) were done and these have always been negative. One worker with coalescent disease gave a history of Brucella infection and the skin test and blood agglutination were positive. At necropsy no evidence of brucellosis was discernible in the lungs or elsewhere. In our experience the clinical, laboratory, x-ray, and pathological evidence does not indicate that concomitant infection plays a significant part in the pathogenesis of the coalescent form of this disease.

INFECTION IN THE NON-COALESCENT FORMS OF THE DISEASE: In workers having linear, reticular or generalized mottled types of fibrosis we have occasionally seen localized apical or sub-apical infiltrates which were radiologically compatible with tuberculosis. Tuberculin skin tests have usually, but not always, been positive in these cases, but bacteriologic studies of the sputum and gastric contents have nearly always been negative. Most of these lesions, formerly presumed tuberculous, have remained stationary or regressed without treatment. However, in a few instances they have progressed, with the subsequent development of open tuberculosis. Four patients with tuberculous cavitation responded, at first somewhat encouragingly, to sanatorium treatment. The cavities closed by "blocking," and sputum specimens became negative for a time but subsequently reverted to positive. On the x-ray films these cavities although closed temporarily by "blocking," (not the most desirable form of cavity closure), later re-opened. Nevertheless, we have never previously observed even temporary "blocking" of tuberculous cavities complicating nodular quartz silicosis. Two patients in the necropsy series died of miliary tuberculosis, and another has recently died of progressive phthisis. Dr. Gardner examined the tissues of the patients with miliary disease and was of the opinion that the pneumoconiosis did not pre-dispose to the tuberculosis. Our consulting pathologists have not yet reported on our most recent death from tuberculosis.

Other complicating infections which we have identified (one each of actinomycosis and chronic lung abscess) have been considered as intercurrent infections, and as not contributing etiologically to the pneumoconiosis. However, one can not say that the pneumoconiosis did not predispose to, or aggravate the infections.

## Conclusions

1. THE INHALATION of diatomaceous earth may produce a distinct type of pneumoconiosis.

2. The inhalation of crude diatomaceous earth and natural powders over a long period of time may produce a benign type of linear pulmonary fibrosis, leading to few if any symptoms and no demonstrable disability.

3. The calcined and flux-calcined powders may occasionally produce a rapidly progressive pulmonary fibrosis or granuloma with massive coalescence, bullous emphysema, extensive pleuritis, cor pulmonale, and not infrequently spontaneous pneumothorax.

4. Massive coalescent pulmonary lesions occasionally have developed in persons whose intradermal skin tests were completely and repeatedly negative to full dosage of standardized tuberculin, and in these cases we have been unable to identify tuberculous infection either during life or at post-mortem with the most sensitive bacteriologic and histologic techniques that were available.

5. When tuberculosis is superimposed on diatomaceous earth pneumoconiosis the infection often pursues a benign course until cavitation supervenes, then the course seems to be slowly downhill in spite of modern treatment including collapse procedures and chemotherapy.

6. Fresh water diatomite appears to be much less toxic for workers engaged in processing this material, even when it is subjected to flux-calcination, than are marine diatomaceous earth products.

(1136 W. 6th St., Los Angeles.)

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