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# THE PREVENTION OF SILICOSIS BY METALLIC ALUMINUM
## II.

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IN a preliminary paper[1] it was shown that the addition of small quantities of metallic aluminum powder almost completely inhibited the solubility of silicious material in the beaker. Six rabbits exposed to quartz dust for six months all showed well developed silicosis. Seven rabbits exposed to quartz dust plus 1 per cent metallic aluminum powder for the same period did not develop silicosis. At that time we were not in a position to state either the manner in which metallic aluminum reduced the solubility of silicious material, or from the animal experiments whether the aluminum was acting locally or systemically, or for what period after the cessation of dusting it would continue to act. This paper reports the further progress of this investigation.

### CHEMICAL EXPERIMENTATION

The technical details pertaining to the various substances used in the experiments are given in an appendix.*

The term "solubility" is used to indicate the concentration of silica in the solution under the conditions as noted, determined colorimetrically,[1] and expressed as parts per million (p.p.m.). The term "reduction in solubility" indicates the difference between the solubility of the silica in the presence of the aluminum powder and its solubility in the absence of aluminum powder. It will be noted that the solubility figures for different samples of quartz with no added aluminum vary considerably. The figures do not refer to an equilibrium solubility of silica but to the actual amount of silica dissolved from a given sample in a given time at a given temperature. In view of the fact that quartz dissolves extremely slowly it is evident that the actual figures in any case will depend upon the surface exposed, *i.e.*, fineness of grinding of the different samples.

In an endeavour to determine the mechanism by which metallic aluminum reduces the solubility of silicious materials the following experiments were conducted.

1. *Flocculation.*—It was noted in solubility determinations on aqueous suspensions of silicious materials that the addition of small amounts of metallic aluminum powder produced a flocculation of the particles whereas untreated suspensions remained in the dispersed phase. The effect of positively- and negatively-charged dyes was then determined on the flocculation and solubility of quartz suspensions.

It is shown in Table I that the negative dyes neither produced flocculation nor appreciably reduced the solubility of the quartz. On the other hand the positive dyes did produce flocculation and a fair degree of reduction in solubility.

The effect on the solubility, particle charge, and mobility produced by the addition of increasing amounts of metallic aluminum powder to quartz suspensions was then determined.

It will be noted in Table II that with 0.036 per cent of extremely fine aluminum the solubility has been reduced by 93 per cent, but the flocculation is very slight, whereas it took 0.9 per cent to produce complete flocculation and neutralization of the charge.

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* For lack of space this appendix is not printed here. It is on deposit with the American Documentation Institute, Washington, D.C.

TABLE I.

EFFECT OF DYES ON FLOCCULATION AND SOLUBILITY OF QUARTZ SUSPENSIONS

| | *Solubility* *$SiO_2$ p.p.m.* | *Per cent Reduction* | *Flocculation* |
|---|---|---|---|
| Quartz suspension (control) | 12.4 | – | absent |
| “ “ + Biebrich scarlet (neg.) | 12.6 | nil | absent |
| “ “ + Eosin (neg.) | 10.0 | 19.0 | absent |
| “ “ + Methylene blue (pos.) | 8.5 | 31.0 | present |
| “ “ + Nile blue (pos.) | 11.0 | 11.0 | present |
| “ “ + Nite blue (pos.) | 4.4 | 64.0 | present |

1 g. quartz and 5 c.c. of 0.1 per cent solution of each dye was diluted to 50 c.c. with distilled water. Pyrex glass containers, 37° C. continuous agitation 20 hours.

2. *Adsorption of dissolved silica on aluminum.*—Knowing the adsorptive properties of aluminum hydroxides and activated oxides, tests were conducted to determine the rate of removal of silica from "solution" and the quantities of these compounds required as compared to metallic aluminum.

It will readily be observed in Tables IIIa and IIIb that metallic aluminum is much less effective in removing silica from "solution" when compared with the activated oxides and hydroxides over a short period of time. However, when using metallic aluminum in large amounts and over longer periods of time, soluble silica

TABLE II.

EFFECT OF VARIOUS AMOUNTS OF METALLIC ALUMINUM POWDER ON THE SOLUBILITY, PARTICLE CHARGE AND MOBILITY OF QUARTZ SUSPENSIONS

| | *Mg. Al Added* | *Solubility* *$SiO_2$ p.p.m.* | *Per cent Reduction* | *Floccu-lation* | **Charge on Particles* | *†Mobility* |
|---|---|---|---|---|---|---|
| 1 g. quartz + 50 c.c. water | 0.00 | 76.0 | – | – | neg. | 3.0 |
| “ + “ | 0.09 | 45.0 | 40.0 | ± | neg. | 2.8 |
| “ + “ | 0.18 | 26.0 | 66.0 | ± | neg. | 2.6 |
| “ + “ | 0.36 | 5.1 | 93.0 | + | neg. | 3.0 |
| “ + “ | 0.91 | 4.4 | 94.0 | ++ | neg. | 3.1 |
| “ + “ | 1.81 | 2.2 | 97.0 | +++ | neg. | 3.7 |
| “ + “ | 2.72 | 1.7 | 98.0 | ++++ | neg. | 2.6 |
| “ + “ | 4.52 | 0.9 | 99.0 | ++++ | neg. | 3.2 |
| “ + “ | 7.24 | 0.9 | 99.0 | almost complete | very small neg.? | 0.0 |
| “ + “ | 9.06 | 0.9 | 99.0 | complete | nil. | 0.0 |

Bakelite containers, continuous agitation 20 hours. 37° C.

* Cataphoretic observations conducted in an Abramson cell.

† Mobility units – cm. per second and per volt per cm.

We acknowledge our thanks to Mr. Newman, of the Department of Physics, University of Toronto, for conducting the experiments on the particle charge and mobility.

TABLES IIIa. AND IIIb.

EFFECT OF ALUMINUM POWDER, ACTIVATED ALUMINUM OXIDE AND ALUMINUM HYDROXIDE ON SODIUM SILICATE AND SOLUBLE QUARTZ SOLUTIONS

TABLE IIIa.

| | *Original Concentration* *$SiO_2$ p.p.m.* | *Final Concentration* *$SiO_2$ p.p.m* | *$SiO_2$ p.p.m. Removed from Solution* |
|---|---|---|---|
| Sodium silicate solution pH 7.5 (control) | 20.7 | 20.4 | – |
| 50 c.c. + 30 mg. $Al_2O_3$ (S-242-5) | 20.7 | 1.2 | 19.5 |
| 50 c.c. + 30 mg. $Al_2O_3$ (S-242-5) | 20.7 | 2.1 | 18.6 |
| 50 c.c. + 10 mg. Al(ii) | 20.7 | 20.8 | nil |
| 50 c.c. + 10 mg. Al(ii) | 20.7 | 20.5 | nil |

TABLE IIIb.

| | *Original Concentration* *$SiO_2$ p.p.m.* | *Final Concentration* *$SiO_2$ p.p.m* | *$SiO_2$ p.p.m. Removed from Solution* |
|---|---|---|---|
| Quartz filtrate pH 7.5 (control) | 89.2 | 90.3 | – |
| 25 c.c. + 7.2 mg. $Al(OH)_3$ (780A) | 89.2 | 76.3 | 12.9 |
| 25 c.c. + 7.2 mg. $Al(OH)_3$ (771-1) | 89.2 | 76.3 | 12.9 |
| 25 c.c. + 4.7 mg. $Al_2O_3$ (S-242-5) | 89.2 | 71.9 | 17.3 |
| 25 c.c. + 2.5 mg. Al (X-422) | 89.2 | 82.7 | 6.5 |

Bakelite tubes 37° C., 20 hours continuous agitation.

Quartz filtrate dialyzed through cellophane.

can be removed to a greater extent, as shown in Chart 1. This is in all probability due to the continuous production of more hydroxide over a longer period.

3. *Adsorption of aluminum on the silicious particle.*—The above experiments did not account for the prompt large reduction in solubility produced by the addition of small amounts of metallic aluminum to silicious materials. It was then assumed that the reverse process might take place, that is, the reduction in solubility might be due to a film of an insoluble aluminum compound being adsorbed on the surface of the silicious particles. The following experiments were conducted to test this assumption.

TABLE IV.

EFFECT OF THE ADDITION OF SMALL AMOUNTS OF METALLIC ALUMINUM TO QUARTZ SUSPENSIONS AT VARIOUS TIME INTERVALS

| *Tube No.* | *Time of Addition of Aluminum (in minutes)* | *$SiO_2$ p.p.m. When Aluminum added* | *$SiO_2$ p.p.m at 30 hours* |
|---|---|---|---|
| 1 | 60 | 3.3 | 2.6 |
| 2 | 120 | 5.8 | 4.8 |
| 3 | 180 | 5.5 | 5.0 |
| 4 | 300 | 10.8 | 9.6 |
| 5 | 360 | 15.4 | 13.1 |
| 6 | 415 | 14.3 | 11.6 |
| 7 | control | – | 31.2 |

1 g. quartz powder, 100 c.c. distilled water used in each test.

25 c.c. quartz suspension removed during agitation for silica determination at stated time intervals; then 1.8 mg. aluminum added.

Bakelite containers 37° C. Continuous agitation.

Table IV shows clearly that the addition of small amounts of aluminum powder stops further "solution" when added at various time intervals, without appreciably removing the dissolved silica from solution. This experiment tended to confirm the theory of adsorption. It was then assumed that the film adsorbed on the quartz particle might be a hydrated aluminum oxide. On this assumption, the solubility of various silicious powders, with and without the addition of 1 per cent metallic aluminum powder, was determined at hydrogen ion concentrations of pH 4 to pH 12. Some of these results are shown in Charts 2, 3 and 4. It will be seen that the addition of aluminum powder inhibits the solubility of silica in the various minerals through the hydrogen ion concentration range pH 6 to pH 11. Above pH 11 and below pH 6 the inhibition appears to be ineffective. This strongly indicates the presence of an insoluble aluminum compound on the surface of the quartz particles, preventing their solution within this pH range.

To demonstrate that the adsorbed hydrated alumina coating, in preventing the solution of silica, depends on the amount present and the surface to be coated solubility tests were conducted on silica smoke (–20 Angström units) and McIntyre quartz (–5μ), with and without the addition of varying amounts of metallic aluminum powder (Chart 5). It is definitely shown in Chart 5, that the amount of aluminum required to reduce the solubility of silica suspensions is dependent on the total surface of the silica particles.

TABLE V.

SOLUBILITY OF QUARTZ IN LOCKE'S SOLUTION WITH AND WITHOUT ALUMINUM POWDER OVER LONG PERIODS OF TIME

| *Days* | *Quartz Control* | *Quartz + 1 p.c. Aluminum* | | *Quartz + 2 p.c. Aluminum* | | *Quartz + 3 p.c. Aluminum* | |
|---|---|---|---|---|---|---|---|
| | *$SiO_2$ p.p.m.* | *$SiO_2$ p.p.m.* | *per cent Reduction* | *$SiO_2$ p.p.m* | *per cent Reduction* | *$SiO_2$ p.p.m* | *per cent Reduction* |
| 34 | 63.7 | 0.7 | 99.0 | 0.5 | 99.0 | 0.5 | 99.0 |
| 68 | 67.5 | 1.4 | 98.0 | 1.4 | 98.0 | 1.4 | 98.0 |
| 94 | 75.6 | 0.3 | 99.0 | 0.3 | 99.0 | 0.3 | 99.0 |
| 133 | 60.7 | 0.3 | 99.0 | 0.3 | 99.0 | 0.3 | 99.0 |
| 320 | 81.3 | 0.3 | 99.0 | 2.8 | 97.0 | 2.8 | 97.0 |
| 385 | 99.5 | 0.3 | 99.0 | 3.9 | 96.0 | 3.3 | 97.0 |

5 g. quartz powder, 500 c.c. distilled water, with the addition of 1, 2, and 3 per cent aluminum were placed in rubber stoppered pyrex flasks and allowed to stand at room temperature with occasional agitation.

CHART 1.

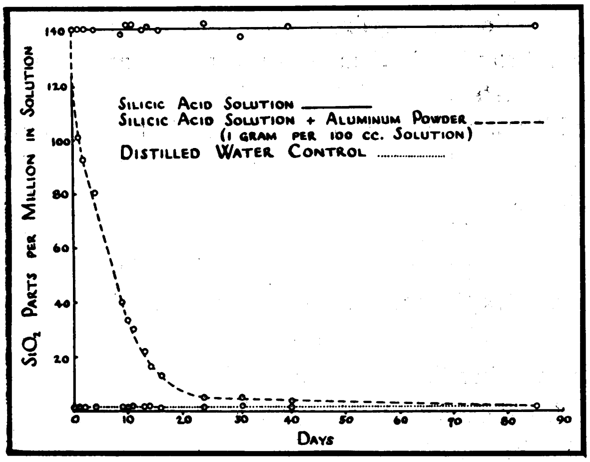


**Chart 1** shows the effect of large amounts of aluminum powder on a solution of silicic acid. Waxed glass containers; room temperature 20° C.; occasional agitation.

The permanency of this adsorbed film on quartz particles was tested in water and physiological solutions (Locke's) for a period of thirteen months. The results obtained in Locke's solution are shown in Table V and are similar to those obtained in water.

In a further experiment a mixture of quartz to which 1 per cent metallic aluminum had been added was placed in Locke's solution. This solution was changed daily for a period of three months. At the conclusion of the experiment there was no increase in the solubility of the quartz.

4. *Staining of the adsorbed film.*—To determine the nature of the adsorbed film samples from the above tests (Table V) taken at various periods, were treated with aurine dye (aurinetricarboxylic acid) which gives a characteristic cherry red colour with aluminum hydroxide. It was difficult to be sure of the dyed film on such small particles under the microscope, so larger pieces of quartz from 1/4 to 8 inch slabs were then treated with metallic aluminum and water for varying periods of time (4 to 38 days), taken out, washed and scrubbed with a brush, and placed in a 2 per cent aqueous solution of aurine, buffered at pH 5.2, heated to 70° C. for five minutes, removed and washed. These pieces stained a cherry red colour, whereas quartz not treated with aluminum and subjected to the dye treatment failed to show any coloration (Fig. 1). Different types of activated oxides and hydroxides of aluminum were used in similar tests, and it was found that the intensity in colour of the dyed surface corresponded closely

CHART 2.

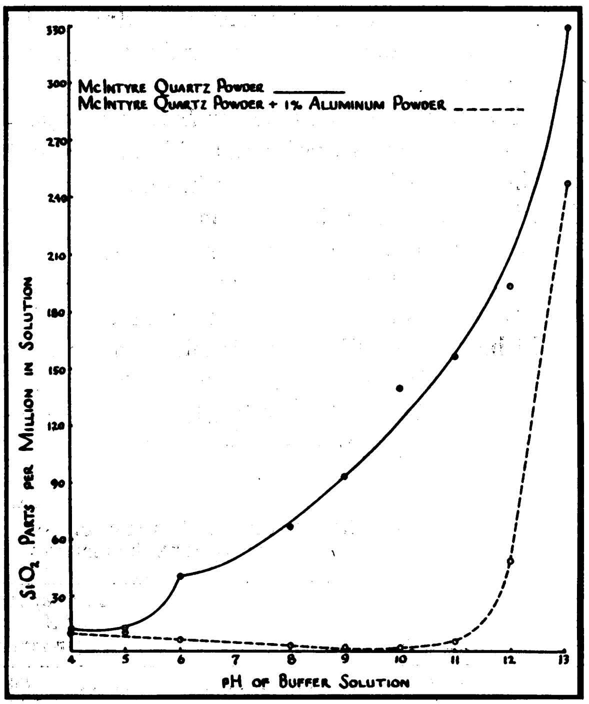


CHART 3.

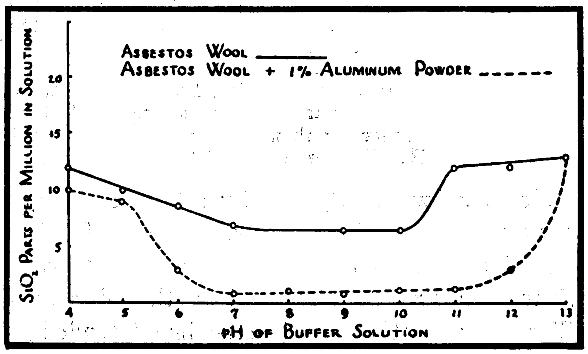
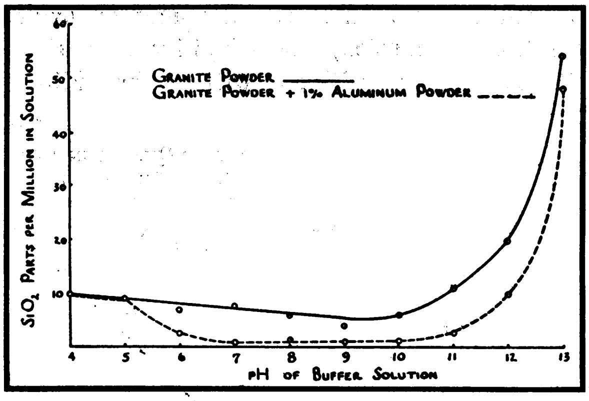


CHART 4.



**Charts 2, 3, and 4** show solubility of various silicious powders, with and without metallic aluminum powder at various hydrogen ion concentrations. One gram powder and 50 c.c. buffer solution used in each test. Temperature 37° C.; continuous agitation, 20 hours; bakelite containers.

to the effect of these compounds in reducing the solubility of quartz (Table VI).

It was found that the stainable film on the surface of aluminum-treated quartz when subjected to solutions more acid than a pH of 4 or more alkaline than a pH of 12 completely disappeared. These samples, when taken from the solution and washed thoroughly, could not be stained with aurine unless again subjected to the aluminum treatment.

CHART 5.

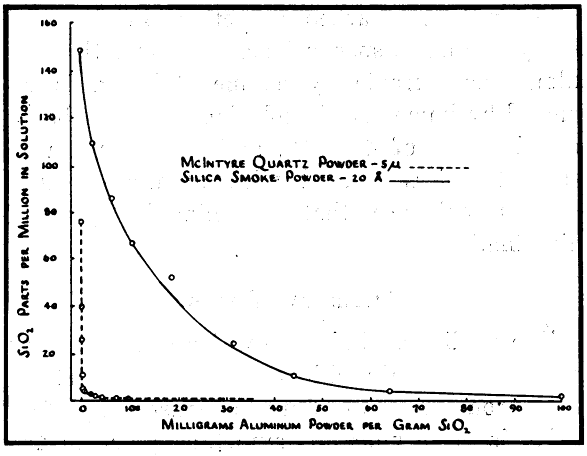


**Chart 5.**—The amount of aluminum necessary to reduce the solubility of silica in relation to particle size. One gram powder + 50 c.c. water used in each test; pyrex glass containers; 37° C., 20 hours' continuous agitation.

5. *Identification of the adsorbed film by the electron diffraction pattern.*—Dr. Lester H. Germer and Mr. K. H. Storks, of the Bell Telephone Laboratories, New York City, have very kindly made a preliminary study of the material which is precipitated upon silica by the reaction of water and aluminum. They have identified this material as a hydrated oxide of aluminum. By a spectroscopic examination of the film scraped from a quartz surface they showed that its silica content was less than 0.5 per cent of its alumina content. After drying the film electron diffraction patterns characteristic of the crystalline alpha aluminum monohydrate ($Al_2O_3.H_2O$) were obtained. The drying was necessary because electron diffraction patterns must be taken *in vacuo*. Since experiments show that the crystalline alpha monohydrate does not stain deeply enough with the aurine dye to account for the observed colour, while the precipitated gelatinous hydrated oxide is deeply stained, it appears probable that the film on the quartz is a gelatinous hydrated oxide of aluminum which is converted into the crystalline monohydrate on drying.*

Following this work tests were made to determine the effect of aluminum mono and trihydrate on the solubility of quartz as compared to metallic aluminum and activated alumina.

TABLE VI.

EFFECT OF ALUMINUM MONO AND TRIHYDRATE ON THE SOLUBILITY OF QUARTZ

| | *Solution $SiO_2$ p.p.m* | *Per cent Reduction* |
|---|---|---|
| Quartz control | 133 | – |
| Quartz + 10 mg. Al(ii) | 4 | 97.0 |
| Quartz + 30 mg. corundum | 131 | – |
| Quartz + 30 mg. activated amorphous alumina (S-242-5) | 15 | 89.0 |
| Quartz + 30 mg. alpha monohydrate (1420 W) | 131 | – |
| Quartz + 30 mg. alpha trihydrate (1413) | 132 | – |

1 g. quartz—50 c.c. water. Bakelite tubes. Continuous agitation 23 hours. 37° C.

This experiment shows clearly that the mono and trihydrate of aluminum have no effect in preventing the solution of the quartz particle; whereas the activated amorphous alumina inhibited the solution by 89 per cent but was not as effective as the metallic powder.

### CHEMICAL DISCUSSION

Gardner[2] has brought forth experimental evidence which strongly suggests that the toxicity of silica is due to that portion of the silica which is in the dispersed colloidal form. Whether or not this theory is correct our experiments seem to show that what we have defined and determined as "solubility" is a measure of the toxicity of the quartz particle. We have demonstrated that the adsorbed film of hydrated aluminum oxide is sufficiently impermeable to prevent silica from passing into what we have defined as "solution," *i.e.*, the state in which it will form silicomolybdic acid.

*Flocculation.*—It has been observed by other workers that aqueous suspensions of quartz powders are flocculated by many substances. Positively charged dyes, the hydroxides of nickel, iron and tin, as well as minerals such as gypsum, and the mineral mixtures present in certain country rocks and shales, all flocculate quartz suspensions. It has been shown (Table

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* Dr. Germer and Mr. Storks are continuing their work, and we understand that they will publish a description of it elsewhere when it is completed. In the meantime, this preliminary statement of their results is made with their approval. The alpha monohydrate is the one often called "Boehmite" in the German literature.

I) that flocculation may be present with very little reduction in "solubility" and (Table II) that a marked reduction in "solubility" can take place with slight flocculation only. The immediate and permanent reduction in the "solubility" of quartz by metallic aluminum can be accounted for only to a slight extent by flocculation brought about by the neutralization of the charge on the quartz particles.

*Adsorption of dissolved silica on aluminum.*—Metallic aluminum in small quantities over a short period of time has been shown to be only slightly effective in removing silica from "solution", while some of the oxides and hydroxides were more efficient. There was found to be a great variation in the adsorptive properties of various types of these compounds, depending on their method of preparation. While larger quantities of the metal did remove silica from "solution", this was undoubtedly due to the production of more hydroxide over a long period of time. This time factor alone shows that the rapid reduction in "solubility" of the silicious particles by small amounts of metal cannot be due to the *removal* of silica from "solution". This is also corroborated by Table IV, where the addition of small amounts of aluminum to quartz suspensions *immediately prevents* further solution without appreciably diminishing the silica in solution.

*Adsorption of aluminum hydroxide on the silicious particle.*—The prevention of further "solution" of quartz suspensions, produced by the addition of [redacted] amounts of metallic aluminum powder [redacted] d that the negative charge on the qu [redacted] was being satisfied by an adsorb [redacted] tively charged hydrated alumina. [redacted] tion of the charge on the suspend [redacted] resulted in their flocculation an [redacted] m of hydrated alumina prevent [redacted] " of the quartz particles. It [redacted] aluminum hydroxide is almost [redacted] soluble within the range pH 5.5 to 8. [redacted] soluble salt when the solution is more [redacted] pH 4 and a soluble aluminate when it is [redacted] alkaline than pH 12. The solubility curves [redacted] various hydrogen ion concentrations of quartz and silicates (Charts 2, 3 and 4) with and without aluminum powder, strongly suggest that removal of the adsorbed film, allowing the rapid solution of the silicious particles, takes place at hydrogen-ion concentrations corresponding to those at which aluminum hydroxide is soluble.

The cherry-red staining with aurine on the surface of quartz after immersion in aqueous suspensions of aluminum and the gelatinous forms of its hydroxides, again strongly suggest the presence of an adsorbed film of gelatinous hydrated alumina. In all cases the aurine-stained film on quartz after treatment with aluminum powder at room temperature has been much more pronounced than that produced by activated oxides and hydroxides including those that produced marked reductions in the solubility of quartz suspensions. The fact that the film, demonstrable by aurine staining, is removed by immersion in solutions above or below a pH range of 4 to 12, and cannot again be stained unless treated with aluminum, adds further evidence that the film is hydrated alumina.*

### ANTIDOTAL ROCKS

The modifying influence which shale, country rock and certain silicates seem to exert on the production of fibrosis caused by free silica is occupying an important place in the investigations of many prominent research workers — King,[3, 4] Brisco,[5] Whitehouse[6] and others. Haldane[7] believed that these antidotal rocks moderated the action of silica in two ways—by dilution and by some form of antagonism. It is of interest in this connection to point out that in the mines of the Porcupine district of Ontario the men working in the crusher houses of the mills do not develop silicosis, although there is approximately 35 per cent of free silica in the mill feed. In a previous paper[8] it was pointed out that animals exposed to this dust, although having large amounts of dust in their lungs, failed to show any fibrosis up to a period of twelve months.

The authors have conducted an investigation into mill feed, country rock and slate obtained [redacted] the Porcupine camp, and although this in [redacted] gation is far from complete they have found [redacted] these three materials, having low silica [redacted] themselves, when added in 50-50 [redacted] to quartz will reduce the solubility [redacted] cent. It was further found that [redacted] es were treated with alkaline

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* [redacted] ess of Dr. Germer and Mr. Stork [redacted] findings have been pointed out above, [redacted] can now be definitely identified as a [redacted] ina.

solutions above pH 12 the antidotal materials had lost their ability to further retard the "solution" of quartz, and aluminum hydroxide was found to be present in the solution. We wish to point out the similarity of the reaction when aluminum-coated quartz is treated in an alkaline solution above pH 12 (Chart 2).

Analysis of these rocks showed them to contain from 10 to 20 per cent of alumina, present chiefly as silicates. The authors believe that the modifying action of antidotal rocks is due in part to the aluminum present, to a slight extent, as free hydroxides derived from the breaking down of these silicates—perhaps connected with the weathering of pyrite or other sulphides present. In the lung these weathered silicates, if present in large amounts, may have the same effect on the silica as they did in the beaker. Gardner[2] has demonstrated that the hydrated oxides of iron when added to quartz, have a definite retarding effect on cellular reaction. We believe that some antidotal rocks may contain considerable quantities of iron, the hydrated oxides of which, by taking silica out of solution, may also be playing a part in the antidotal mechanism.

From the experiments recorded in this paper, those in a previous communication, and from experiments that space does not permit recording here, it has been shown definitely that metallic aluminum prevents "solution" of quartz and silicious materials in three ways: to some extent either by flocculation, or the removal of silica from "solution" by adsorption, but chiefly by coating the mineral particles with gelatinous hydrated alumina that almost entirely prevents their solution. The solution-preventing action of the gelatinous layer of hydrated aluminum seems to be responsible for the powerful effect of the small amounts of metallic aluminum required to inactivate quartz particles, as compared to the large amounts of other protective agents required, such as gypsum, iron oxides, etc.

## ANIMAL EXPERIMENTATION

The animal experiments consisting of three main groups were carried out to determine (1) whether the inactivation of quartz by aluminum was a local or systemic reaction; (2) the tissue reaction produced by the injection of quartz powder, the solubility of which, prior to injection, had been progressively depressed by the addition of increasing amounts of aluminum; (3) the reaction produced in the lungs by the retention of inhaled aluminum dust, quartz dust and mixtures of quartz and aluminum dusts, when breathed in varying proportions either separately or as admixtures. During the course of the different experiments numbers of the rabbits died from infections. Those animals were discarded in which the infective process in any way obscured the reaction produced by the presence of dust and are not included in the data recorded below.

1. *Local or systemic reaction.*—To ascertain whether aluminum powder was acting locally or systemically in preventing fibrosis the following experiments were conducted. (*a*) Rabbits were fed metallic aluminum powder in their rations, 10 mg. each, daily, and dusted for twelve hours with quartz dust. (*b*) Rabbits were injected subcutaneously, intramuscularly, intraperitoneally, and intravenously, with varying amounts of metallic aluminum powder at various intervals while being subjected to quartz dust, twelve hours daily. (*c*) Subcutaneous injections of 10 mg. of $-5\mu$ quartz were made into the backs of a series of rabbits, and they were then exposed to aluminum dust twelve hours daily. (*d*) To another series of rabbits injected subcutaneously with quartz only, weekly intravenous injections of varying concentrations of metallic aluminum powder were given.

Animals from these groups were killed at various intervals, and sections for microscopic examination prepared from lungs, liver, spleen, kidney and the areas injected with quartz. Microscopically there was no evidence found to indicate that aluminum was acting systemically. Animals in groups *a* and *b* developed fibrosis to the same extent and at the same rate as control animals dusted with quartz only. In gro[illegible] and *d* fibrotic nodules developed at th[illegible] and were of the same charact[illegible] the controls.

2. *Amount of al*[illegible]*tivate quart*[illegible]ween the solubi[illegible]e amount of [illegible]o inactivate quartz, [illegible]d the stability of the [illegible]na coating on the quartz particles [illegible]ined by the following experiments. Samples of $-5\mu$ quartz were prepared by grinding quartz on quartz and separating by air-sedimentation. To these samples varying amounts of metallic aluminum powder were

## PLATE I.

PHOTOGRAPHS REPRODUCED IN NATURAL COLOURS FROM KODACHROME FILMS.

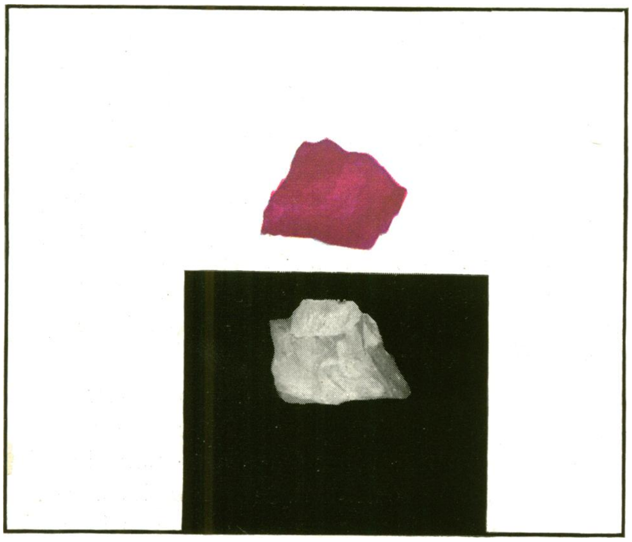
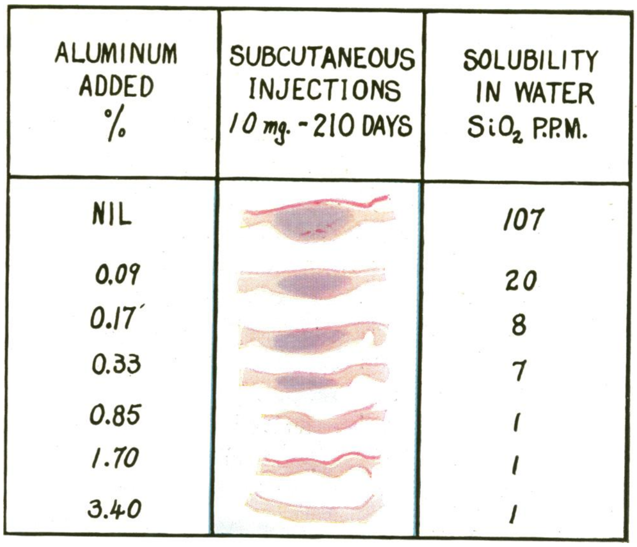


Fig. 1



| ALUMINUM ADDED % | SUBCUTANEOUS INJECTIONS 10 mg. - 210 DAYS | SOLUBILITY IN WATER $SiO_2$ P.P.M. |
|---|---|---|
| NIL | | 107 |
| 0.09 | | 20 |
| 0.17 | | 8 |
| 0.33 | | 7 |
| 0.85 | | 1 |
| 1.70 | | 1 |
| 3.40 | | 1 |

Fig. 2

Fig. 3

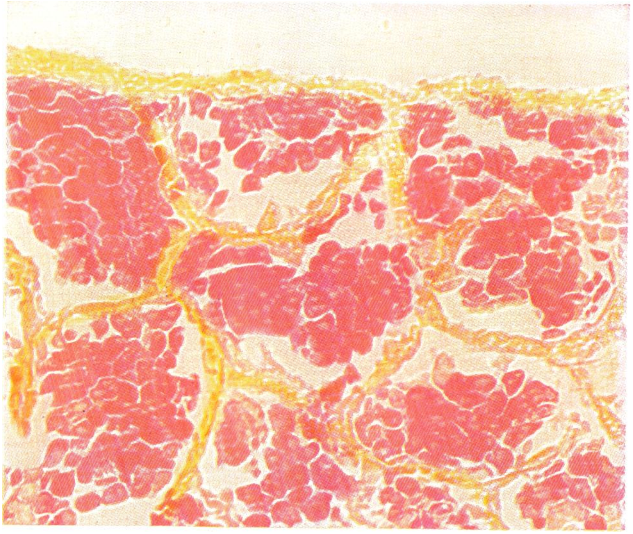


Fig. 4

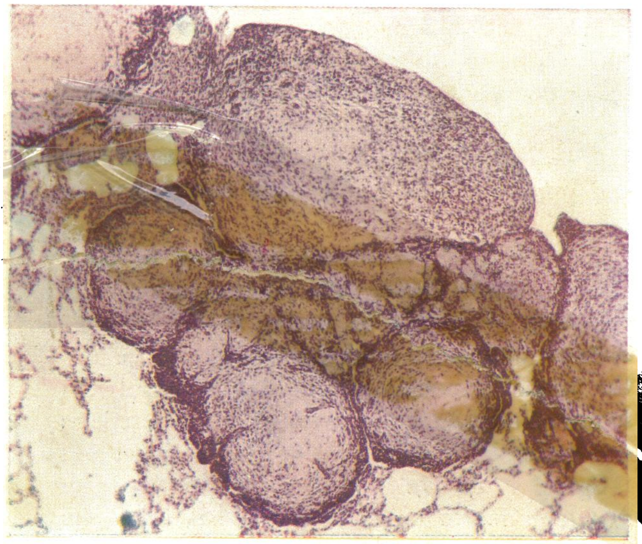


Fig. 5

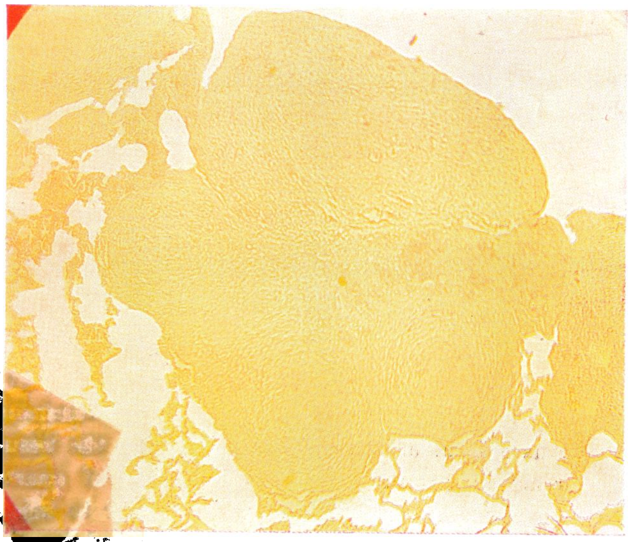


Fig. 6

**Fig. 1.**—Upper quartz coated with hydrated alumina, [illegible]ted to aurine dye treatment (red stained). Lower quartz uncoated but [illegible] same dye treatment ([illegible]inable). **Fig. 2.**—This series of quartz injections was made into the back of [illegible]. **Figs.** 3, 5, 7, [illegible] 11.—Stained with routine hæmatoxylin and eosin. **Figs.** 4, 6, 8, 10, 12.—Stained with [illegible] demonstrate presence of re[illegible]ining hydrated alumina. **Figs. 3 and 4.**—Typical foreign-body response [illegible] dust. **Figs. 5** [illegible]—[illegible]cal nodular fibrosis produced by quartz dust. Note absence of any [illegible]

## PLATE II.

PHOTOGRAPHS REPRODUCED IN NATURAL COLOURS FROM KODACHROME FILMS.

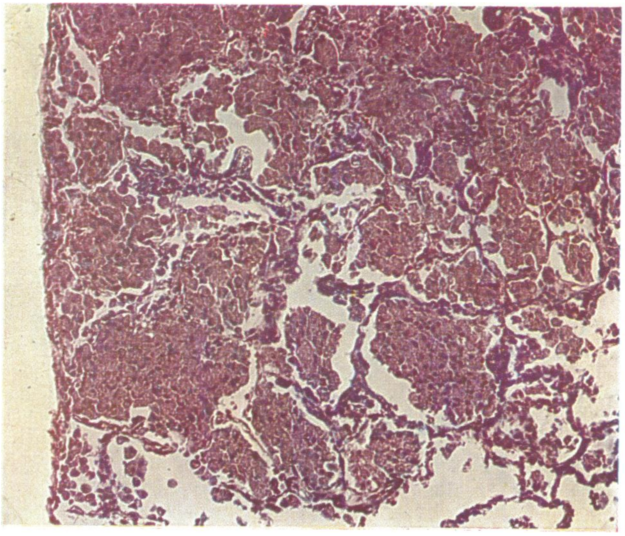


Fig. 7

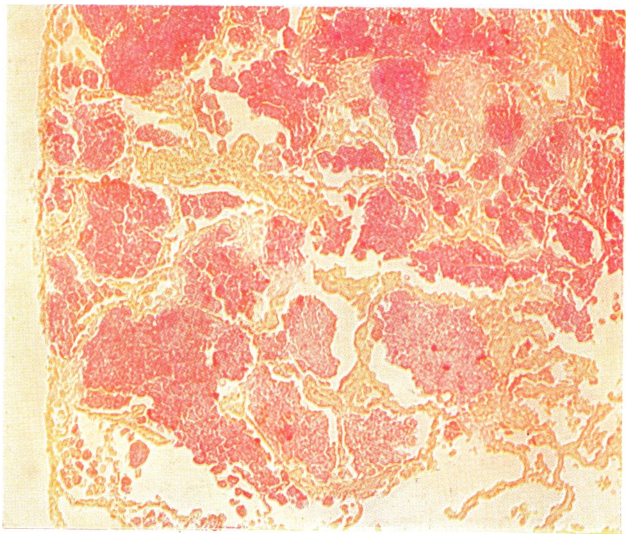


Fig. 8

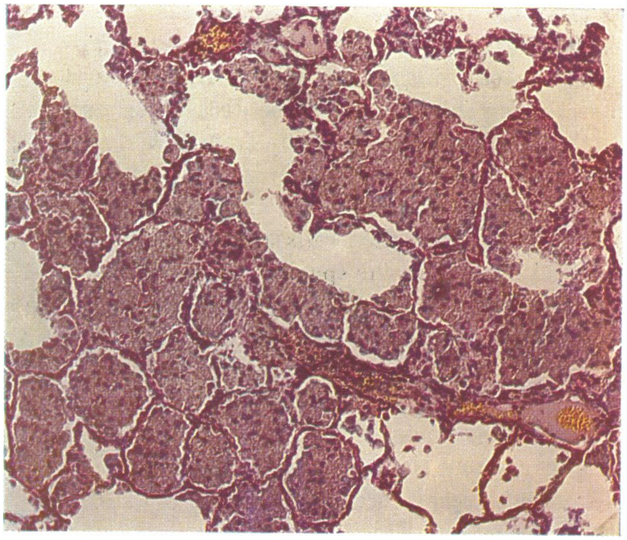


Fig. 9

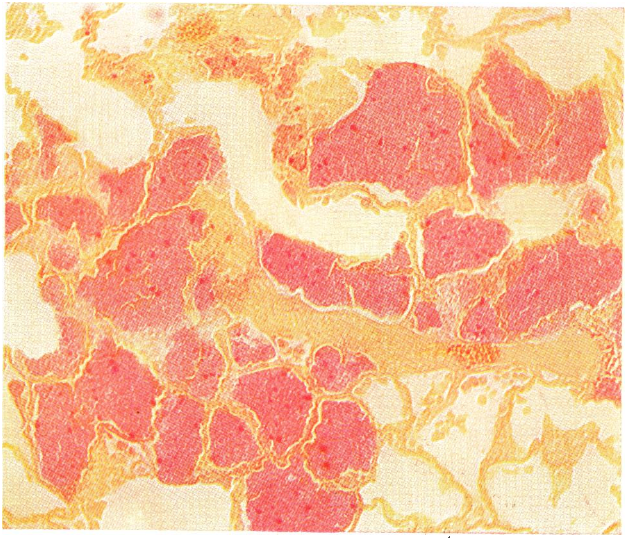


Fig. 10

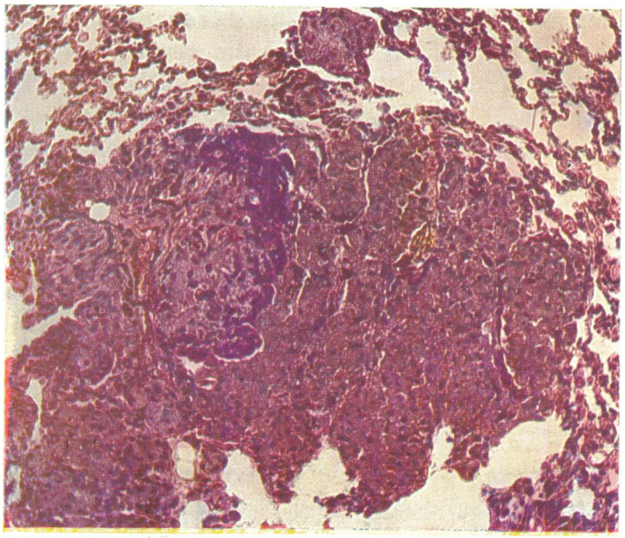


Fig. 11

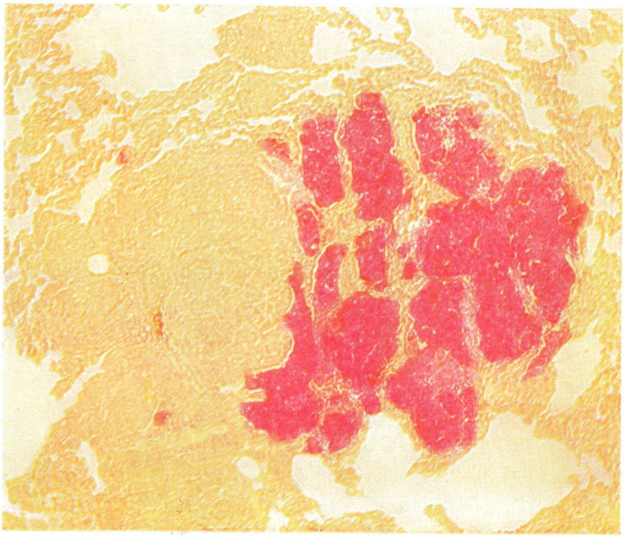


Fig. 12

**Figs. 7 and 8.**—Typical foreign-body response produced by admixture of quartz and aluminum. **Figs. 9 and 10.**—Typical foreign-body response produced by daily dusting with aluminum for 40 minutes before or after the 12 hours quartz dusting. **Figs. 11 and 12.**—Silicotic rabbit subsequently dusted with aluminum 20 minutes daily. Note presence of alumina in quartz containing dust cells showing foreign-body reaction and absence of alumina in areas of early fibrosis.

added and the solubility of the mixtures determined in water after twenty hours' agitation. Ten mg. amounts of all these samples were then injected into each of several rabbits, and cross-sections of the injected areas examined microscopically at two and seven months. At two months the sections of the injected areas showed nodular fibrosis with metallic aluminum concentrations up to 0.33 per cent and a foreign-body reaction with 0.85 per cent or greater. At seven months this picture was unchanged (Fig. 2).

3. *Dusting experiments.* — The methods of dusting and the apparatus used in repeating the original experiments at the McIntyre mine were the same as described in our first paper.[1] In the experiments conducted at the Department of Medical Research, however, tube mills, lined with rubber, were used instead of quartz lined tumble boxes, as tests had shown practically no wear on this special rubber liner and contamination of the quartz dust was negligible. The mills were easy to install and required a minimum amount of attention. The cages were designed to house 12 rabbits each, and were arranged in groups to take care of various types of dusting. Each cage was connected to a negative pressure ventilating system and care taken to avoid dust contamination from group to group. At weekly intervals the ventilating system was checked with an anemometer, dust counts estimated by the Franks photo-electric machine,[9] and particle size determined. The total $SiO_2$ and total aluminum content as well as the solubility of the dust in the various cages were also determined.

All dusted animals, the findings on which are recorded below, except the aluminum controls, were exposed for varying periods of time to different concentrations, as noted, of quartz and/or aluminum dust of approximately 20,000 particles per c.c., the majority being under 3 microns in diameter. At various intervals animals were killed to determine the amount of dust in the lungs and the type of tissue response. Portions of all lungs were assayed chemically to determine the amount of quartz and aluminum present. The aluminum assays have been expressed as milligrams of the metal per 100 g. of the dried tissue. The microscopic sections were prepared in the same manner as stated in our first paper.

*Aluminum control animals.*—Rabbits were exposed to aluminum dust to determine the effect of inhaled aluminum in the lung and on the general health of the animals over long periods of time. Eight rabbits were exposed to an atmosphere containing freshly ground finely particulate aluminum powder in a concentration averaging 7,000 particles per c.c., 12 hours daily for 14 months. Following cessation of the dust exposure some of the animals were observed for an additional seven months. Chemical assay of the lungs showed them to contain from 270 to 1,200 mg. of aluminum per 100 g. of dried tissue. During their life-time these animals gained normally in weight, and from the appearance and texture of the fur and their general behaviour there was no evidence of any harmful effect due to the inhalation of the aluminum dust.

The gross and microscopic examination of the tissues apart from the lungs showed them to be normal. In the gross the lungs showed a uniform dark mottling of the pleural surfaces and on sectioning this was seen to be distributed uniformly throughout. Apart from this the lungs appeared normal. Microscopic examination showed the mottled areas, seen in the gross, to be aggregates of dust cells almost completely filling adjacent alveolar spaces. These cells contained irregular shaped opaque particles, the majority being under $3\mu$ in diameter. Practically all these particles were present in the dust cells. These cells presented regular outlines and their nuclei stained well. The alveolar walls throughout the lung showed no evidence of thickening except occasionally in the dust-containing areas. This thickening consisted of a slight alveolar endothelial proliferation. The ciliated epithelial lining of the bronchial tree appeared normal. The lymphatic spaces and aggregates throughout the lung contained relatively few dust-laden cells, and showed no evidence of thickening or damage. The opaque particles seen in the dust cells were observed to give off bubbles and completely disappear when a drop of 6N NaOH was placed on a section under a cover slip. Sections stained with aurine showed the cytoplasm of these dust cells to contain varying concentrations of a cherry red colour (Figs. 3 and 4).

*Quartz controls.*—All the control animals used for the various experiments were housed in a separate group of cages and received quartz dust for twelve hours daily. As recorded in Table VII practically all these animals from five months on showed the nodulations typical of

### TABLE VII.

### QUARTZ DUSTING ONLY—12 HOURS DAILY

| | | | *Lung assay* | | *Fibrosis present in* | | | |
|---|---|---|---|---|---|---|---|---|
| *Rabbit number* | *Period of dusting (days)* | *Removal from dust (days)* | **Mg. per cent Al* / *Mg. per cent SiO₂* × *100* = | *Percentage* | *Peribronchial lymphatics* | *Perivascular lymphatics* | *Alveoli* | *Alveolar wall thickening non-fibrotic* |
| 209 | 105 | 0 | 2.8/585 | 0.5 | - | - | - | - |
| 165 | 105 | 0 | 22/5500 | 0.4 | + | - | - | - |
| C | 120 | 0 | 16/1200 | 1.3 | + | - | - | - |
| 466 | 120 | 0 | 1.8/340 | 0.5 | - | - | - | + |
| 513 | 123 | 0 | 3.9/3200 | 0.1 | - | - | - | - |
| 377 | 128 | 0 | .2/185 | 0.1 | - | - | - | - |
| 461 | 129 | 0 | 4.1/810 | 0.5 | - | - | - | - |
| 375 | 134 | 0 | 1/234 | 0.4 | - | - | - | - |
| 580 | 138 | 0 | 1.8/660 | 0.3 | - | - | - | + |
| 214 | 138 | 0 | 6.6/1420 | 0.5 | + | - | - | - |
| 206 | 138 | 0 | 6/810 | 0.7 | + | - | - | - |
| 90 | 151 | 0 | 4.5/1010 | 0.4 | - | - | - | - |
| 89 | 161 | 0 | 3.6/540 | 0.7 | + | - | - | - |
| 788 | 163 | 131 | 17/3980 | 0.4 | + | - | - | + |
| 779 | 163 | 188 | 23/4510 | 0.5 | + | - | - | + |
| 510 | 167 | 0 | 10.9/5906 | 0.2 | + | + | - | - |
| 70 | 172 | 0 | 4.4/487 | 0.9 | - | - | - | + |
| 562 | 173 | 0 | 5.8/5450 | 0.1 | - | - | - | + |
| 581 | 175 | 0 | 3.7/1150 | 0.3 | + | - | - | ++ |
| 756 | 177 | 0 | 2.5/2720 | 0.1 | + | - | - | - |
| 4C | 178 | 0 | 4.5/550 | 0.8 | + | - | - | - |
| 151 | 180 | 0 | 12/6550 | 0.2 | ++ | ++ | + | + |
| 104 | 180 | 0 | 1.3/4280 | 0.0 | ++++ | ++++ | ++++ | ++ |
| 774 | 180 | 0 | 10/3900 | 0.2 | - | ++ | + | ++ |
| 770 | 183 | 0 | 33/5720 | 0.6 | - | - | - | + |
| 508 | 193 | 0 | 4.5/3400 | 0.1 | - | - | - | + |
| 1C | 201 | 0 | 8.4/4320 | 0.2 | ++ | ++ | ++ | + |
| 166 | 215 | 0 | 28/8740 | 0.3 | +++ | +++ | ++ | + |
| 222 | 219 | 0 | 5.4/885 | 0.6 | - | - | - | - |
| 344 | 230 | 0 | 5.4/1570 | 0.3 | - | - | - | - |
| 764 | 233 | 13 | 11.6/7370 | 0.1 | + | + | + | +++ |
| 753 | 233 | 25 | 13/4650 | 0.3 | + | + | - | + |
| 751 | 233 | 55 | 25/7140 | 0.3 | + | + | + | + |
| 771 | 233 | 102 | 42/6700 | 0.6 | + | ++ | + | ++ |
| 761 | 233 | 207 | 23/5130 | 0.4 | ++ | ++ | ++ | ++ |
| 62 | 252 | 0 | 2.9/965 | 0.3 | + | + | - | + |
| 336 | 294 | 0 | 3.9/3900 | 0.1 | + | + | - | + |
| 156 | 300 | 0 | 20/5710 | 0.3 | ++ | + | - | + |
| 152 | 300 | 0 | 3.2/1020 | 0.3 | ++ | + | + | + |
| 153 | 300 | 0 | 13/2850 | 0.4 | ++ | ++ | ++ | ++ |
| 343 | 301 | 0 | 3.5/930 | 0.1 | + | - | - | - |
| 239 | 303 | 0 | 1.8/950 | 0.2 | + | - | - | - |
| 583 | 324 | 39 | 9.1/2360 | 0.3 | ++ | ++ | ++ | ++ |
| 227 | 335 | 0 | 23/10800 | 0.2 | + | + | ++ | + |
| 236 | 343 | 0 | 14/3240 | 0.4 | + | - | - | - |
| 527 | 345 | 135 | 11/9700 | 0.1 | ++ | ++ | ++ | ++ |
| 506 | 345 | 137 | 7/1470 | 0.5 | ++ | ++ | ++ | ++ |
| 205 | 364 | 0 | 113/9430 | 1.2 | + | + | - | + |
| 339 | 370 | 0 | 12/1990 | 0.6 | + | - | + | ++ |
| 488 | 378 | 131 | 11/2460 | 0.4 | ++ | ++ | + | +++ |
| 479 | 380 | 210 | 20/6200 | 0.3 | +++ | +++ | ++++ | ++ |
| 215 | 388 | 20 | 23/4650 | 0.5 | ++ | ++ | + | ++ |
| 212 | 388 | 210 | 5/630 | 0.8 | ++ | ++ | + | ++ |
| 208 | 388 | 210 | 16/2860 | 0.5 | ++ | ++ | ++ | ++ |
| 398 | 398 | 210 | 14/4210 | 0.3 | ++ | ++ | ++ | +++ |
| 84 | 412 | 210 | 24/4740 | 0.5 | ++ | ++ | +++ | ++ |
| 232 | 415 | 39 | 3.4/2090 | 0.2 | ++ | ++ | ++ | ++ |
| 230 | 415 | 210 | 5.4/2000 | 0.3 | ++ | ++ | ++ | ++ |
| 91 | 590 | 0 | 6.4/6500 | 0.1 | ++ | ++ | ++ | + |

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*This equation actually represents the ratio of quartz to aluminum and not the true percentage. Due to the fact that they are practically the same and we have used percentage throughout the paper we have used this term in order not to confuse the reader.

\+ =slight amount of fibrosis.  
++ =moderate " " "  
+++ =marked " " "  
++++ =massive " " "

TABLE VIII.

ADMIXTURE OF QUARTZ AND ALUMINUM DUSTS—12 HOURS DAILY

| Rabbit number | Period of dusting (days) | Removal from dust (days) | *Lung assay* | | *Fibrosis present in* | | | Alveolar wall thickening non-fibrotic |
|---|---|---|---|---|---|---|---|---|
| | | | *Mg. per cent Al / Mg. per cent $SiO_2$ × 100 = | Percentage | Peri-bronchial lymphatics | Peri-vascular lymphatics | Alveoli | |
| ALUMINUM PERCENTAGE–0.5 | | | | | | | | |
| 137 | 118 | 0 | 2.3/607 | 0.4 | - | - | - | - |
| 175 | 118 | 0 | 2.7/1000 | 0.3 | - | - | - | - |
| 313 | 163 | 0 | 2.4/695 | 0.3 | - | - | - | + |
| 312 | 163 | 45 | 2.4/1170 | 0.2 | - | - | - | + |
| 104 | 174 | 0 | 6.4/1780 | 0.4 | - | - | - | - |
| 355 | 174 | 0 | 3.7/2540 | 0.1 | - | - | - | + |
| 428 | 232 | 0 | 3.4/1490 | 0.2 | - | - | - | + |
| 539 | 282 | 0 | 4.6/1380 | 0.3 | - | - | - | + |
| 429 | 301 | 0 | 2.8/665 | 0.4 | - | - | - | + |
| 423 | 324 | 0 | 8.8/4030 | 0.2 | - | - | - | + |
| 567 | 325 | 210 | 19/4610 | 0.4 | + | + | - | ++ |
| 489 | 383 | 195 | 5.2/1850 | 0.3 | + | + | + | ++ |
| 474 | 389 | 165 | 6.7/2670 | 0.2 | + | + | + | ++ |
| 473 | 389 | 202 | 0.9/2440 | 0.0 | + | + | + | ++ |
| 378 | 390 | 150 | 21/4980 | 0.4 | + | + | + | ++ |
| 396 | 403 | 210 | 39/8500 | 0.4 | + | + | + | ++ |
| 317 | 413 | 157 | 32/6930 | 0.5 | - | - | - | ++ |
| 105 | 431 | 135 | 21/4280 | 0.5 | + | + | + | ++ |
| 150 | 431 | 210 | 26/6130 | 0.4 | + | + | + | ++ |
| ALUMINUM PERCENTAGE 0.5 TO –1.0 | | | | | | | | |
| 435 | 382 | 0 | 31/3890 | 0.8 | - | - | - | + |
| 422 | 398 | 120 | 16/2840 | 0.5 | - | - | - | - |
| 330 | 403 | 210 | 51/5670 | 0.9 | - | - | - | ++ |
| 160 | 404 | 0 | 61/8500 | 0.7 | - | - | - | +++ |
| 128 | 431 | 30 | 58/7750 | 0.7 | - | - | - | ++ |
| 147 | 431 | 210 | 5.2/825 | 0.6 | + | + | + | ++ |
| 148 | 431 | 210 | 16/3100 | 0.5 | + | + | - | ++ |
| 111 | 431 | 37 | 32/4200 | 0.7 | + | + | + | ++ |
| 362 | 431 | 210 | 27/5030 | 0.5 | - | - | - | ++ |
| ALUMINUM PERCENTAGE 1.0 TO –1.5 | | | | | | | | |
| 499 | 149 | 0 | 52/3800 | 1.4 | - | - | - | - |
| 363 | 237 | 0 | 17/1240 | 1.4 | - | - | - | - |
| 384 | 262 | 0 | 33/2540 | 1.3 | - | - | - | + |
| 132 | 342 | 0 | 50/4850 | 1.0 | - | - | - | + |
| 392 | 389 | 0 | 49/4550 | 1.1 | - | - | - | ++ |
| 365 | 398 | 0 | 49/4360 | 1.1 | - | - | - | + |
| 292 | 403 | 210 | 88/7200 | 1.2 | - | - | + | + |
| 359 | 431 | 67 | 87/6250 | 1.4 | - | - | - | ++ |
| 183 | 431 | 97 | 68/5280 | 1.3 | - | - | + | + |
| 189 | 431 | 135 | 110/10200 | 1.1 | + | + | + | ++ |
| ALUMINUM PERCENTAGE 1.5 TO –2.0 | | | | | | | | |
| 459 | 142 | 0 | 3.7/242 | 1.5 | - | - | - | - |
| 177 | 174 | 0 | 72/3690 | 1.9 | - | - | - | + |
| 490 | 179 | 0 | 34/2180 | 1.6 | - | - | - | - |
| 188 | 223 | 0 | 16/1000 | 1.6 | - | - | - | - |
| 540 | 271 | 0 | 24/1550 | 1.5 | - | - | - | ++ |
| 131 | 418 | 0 | 119/6420 | 1.9 | - | - | - | ++ |
| 185 | 431 | 97 | 170/9750 | 1.7 | - | - | - | + |
| ALUMINUM PERCENTAGE +2.0 | | | | | | | | |
| 407 | 204 | 0 | 130/3460 | 3.8 | - | - | - | + |
| 349 | 262 | 0 | 84/3500 | 2.4 | - | - | - | + |
| 333 | 289 | 0 | 63/2120 | 3.0 | - | - | - | + |
| 408 | 297 | 0 | 117/4040 | 2.9 | - | - | - | + |
| 180 | 396 | 0 | 119/5080 | 2.3 | - | - | - | ++ |
| 346 | 420 | 0 | 79/3180 | 2.5 | - | - | - | + |

*This equation actually represents the ratio of quartz to aluminum and not the true percentage. Due to the fact that they are practically the same and we have used percentage throughout the paper we have used this term in order not to confuse the reader.

\+ =slight amount of fibrosis.
++ =moderate " " "
+++ =marked " " "
++++ =massive " " "

*Note.*—The aluminum percentage above represents the total aluminum present. Allowance must be made for the average amount present in control animals.

### TABLE IX.

### QUARTZ DUSTING 12 HOURS, ALUMINUM DUSTING 40 MINUTES DAILY

| | | | *Lung assay* | | *Fibrosis present in* | | | |
|---|---|---|---|---|---|---|---|---|
| *Rabbit number* | *Period of dusting (days)* | *Removal from dust (days)* | $\frac{\text{*Mg. per cent Al}}{\text{Mg. per cent SiO}_2} \times 100 =$ | *Percentage* | *Peribronchial lymphatics* | *Perivascular lymphatics* | *Alveoli* | *Alveolar wall thickening non-fibrotic* |
| | | | ALUMINUM PERCENTAGE -0.5 | | | | | |
| 647 | 136 | 0 | 7.5/2880 | 0.5 | - | - | - | + |
| | | | ALUMINUM PERCENTAGE 0.5 TO -1.0 | | | | | |
| 796 | 161 | 150 | 35/3890 | 0.8 | - | - | - | + |
| 784 | 161 | 120 | 3.6/695 | 0.5 | - | - | - | - |
| 777 | 161 | 28 | 42/4480 | 0.9 | - | - | - | - |
| 642 | 206 | 0 | 50/990 | 0.5 | - | - | - | - |
| 640 | 206 | 0 | 5/940 | 0.5 | - | - | - | - |
| 649 | 274 | 0 | 74/7800 | 0.9 | - | - | - | + |
| 641 | 285 | 187 | 30/3380 | 0.9 | - | - | - | + |
| 631 | 285 | 120 | 100/11900 | 0.8 | - | - | - | + |
| 638 | 285 | 127 | 43/8600 | 0.5 | - | - | - | + |
| 633 | 285 | 81 | 40/6500 | 0.6 | - | - | - | ++ |
| | | | ALUMINUM PERCENTAGE 1.0 TO -1.5 | | | | | |
| 795 | 180 | 0 | 34/3110 | 1.1 | - | - | - | - |
| 643 | 225 | 0 | 76/5570 | 1.4 | - | - | - | - |
| 620 | 244 | 0 | 70/6500 | 1.1 | - | - | - | - |
| 618 | 270 | 0 | 70/5420 | 1.3 | - | - | - | - |
| 624 | 285 | 97 | 126/10200 | 1.2 | - | - | - | - |
| 750 | 285 | 67 | 44/4070 | 1.1 | - | - | - | + |
| 648 | 285 | 75 | 92/6360 | 1.4 | - | - | - | + |
| 634 | 285 | 97 | 68/6000 | 1.1 | - | - | - | ++ |
| | | | ALUMINUM PERCENTAGE 1.5 TO -2.0 | | | | | |
| 625 | 222 | 0 | 110/6900 | 1.6 | - | - | - | - |
| 619 | 285 | 97 | 120/6180 | 1.9 | - | - | - | + |
| | | | ALUMINUM PERCENTAGE +2.0 | | | | | |
| 626 | 164 | 0 | 190/6350 | 3.0 | - | - | - | - |
| 622 | 171 | 0 | 43/1950 | 2.2 | - | - | - | - |
| 616 | 285 | 15 | 150/6450 | 2.4 | - | - | - | - |

***This equation actually represents the ratio of quartz to aluminum and not the true percentage. Due to the fact that they are practically the same and we have used percentage throughout the paper we have used this term in order not to confuse the reader.**

**+ = slight amount of fibrosis.**
**++ = moderate " " "**
**+++ = marked " " "**
**++++ = massive " " "**

***Note.*—The aluminum percentage above represents the total aluminum present. Allowance must be made for the average amount present in control animals.**

silicosis, occurring first in the peribronchial and perivascular lymphatics and later in the alveoli. A detailed description of the pathological findings is not given here as they are the same as reported in our preliminary paper.[1] It will be observed that the aluminum content of these lungs varies considerably. This is due to the varying amounts of aluminum silicates known to be present in the quartz used for dusting. No hydrated alumina could be demonstrated in any of these lungs by the aurine staining method (Figs. 5 and 6).

*Admixtures of quartz and aluminum.*—Quartz and aluminum pellets were ground together to produce variable mixtures of dust in different cages containing approximately ½, 1, 2, 3 per cent of aluminum, in order to determine the minimum concentration necessary to prevent fibrosis. The findings in these animals are tabulated in Tables VIII and IX according to the percentage of total aluminum found in the lungs in relation to the silica content. It was not possible, by direct chemical assay, to distinguish between the amount of aluminum derived from the silicates present in the quartz, and that from the inhaled aluminum powder. The amount of aluminum derived from the inhaled aluminum powder can be determined indirectly by deducting from the total aluminum content the average percentage (0.4) of aluminum present in the lungs of the control animals. When this blank is deducted it will be seen from Table VIII that the lungs of some animals having less than 1 per cent aluminum show fibrosis. These lungs presented a striking contrast when compared with those lungs containing more than 1 per cent aluminum. However, the fibrosis present in the lungs of these animals was not as extensive as that observed in the control animals having comparable exposures.

The hydrated alumina demonstrable by aurine staining in these lungs had a patchy distribution. *The outstanding finding was the absence of fibrosis in all areas where demonstrable hydrated alumina was present, whereas in those areas showing fibrosis no hydrated alumina could be detected* (Figs. 7, 8, 9 and 10).

*Alternate dusting with quartz and aluminum.*—The question arose as to whether it was necessary to have aluminum dust intimately mixed with the silicious dust during inhalation or could the same objective be attained by the alternate dusting with aluminum and quartz. As this would be of importance in the practical application of aluminum dust for the prevention of silicosis the following experiments were conducted.

A group of animals was exposed for twelve hours daily to quartz dust (20,000 particles per c.c.) then transferred to a cage where they received aluminum dust (7,000 particles per c.c.) for 40 minutes. Another group received 40 minutes of aluminum dusting prior to the 12 hours of quartz dusting.

The findings in these animals are recorded in Table IX. *No evidence of fibrosis was observed in the lungs of these animals.* The dust present in these lungs produced only a foreign body reaction similar to that described in detail in a preliminary paper.[1] The most important finding was the uniform distribution of the hydrated alumina *intimately mixed* with the quartz particles. This contrasted with the *patchy distribution* seen in the animals exposed to admixed quartz and aluminum dust (Figs. 9 and 10).

## PATHOLOGICAL DISCUSSION

All the experimental evidence indicates that the inactivation of quartz by aluminum is not a systemic reaction but takes place only when aluminum is closely associated with quartz in body cells or fluids. It has been shown by subcutaneous injections and dusting experiments that the minimum amount of metallic aluminum necessary to inactivate quartz in tissues is 1 per cent when *uniformly* mixed with quartz.

The method used in these experiments to produce an admixture of quartz and aluminum dust was not entirely satisfactory. While chemical analysis and solubility tests indicated a sufficient percentage of aluminum to inactivate the quartz, the size of the aluminum particles varied considerably. Following recharging of the boxes or mills most of the aluminum dust produced for a few days was too coarse to gain entry to the lung. As grinding progressed the aluminum dust produced was considerably finer, the majority of the particles being less than 3$\mu$ in diameter. We believe that this accounts for the patchy distribution of the aluminum and the areas of nodules containing no demonstrable aluminum in the lungs of the animals dusted with admixtures of quartz and aluminum. In spite of this faulty distribution these animals developed less fibrosis and at a much slower rate than the control animals. A better procedure to follow would be to introduce into the cages containing the quartz dust a desired quantity of aluminum powder (–3$\mu$) from an independent source.

The aluminum dust to which the group of rabbits was exposed for 40 minutes daily was produced by grinding aluminum pellets together. This dust was constantly uniform, most of the particles being under 3$\mu$ in diameter, which accounts for the uniform distribution of the stainable hydrated alumina in the lungs of these animals and the absence of any fibrosis.

At the present time we have no evidence to indicate how long the coating of hydrated alumina will continue to inactivate quartz in the lung. The stability of the hydrated alumina coating through the hydrogen ion concentration range corresonding to that of the normal lung tissues and the inactivation of quartz in the dusted animals for periods up to 17 months indicate that it is relatively permanent. We do not believe, however, that the factor of the permanency of the coating is of primary importance. This is indicated by results obtained on a group of silicotic rabbits exposed daily to aluminum dust for a period of 20 to 60 minutes and killed at intervals from one to six months. Sections of these lungs indicate that the aluminum dust is being engulfed mainly by the quartz containing dust cells (Figs. 11 and 12), and that the further solution of these particles is prevented, halting further progression of fibrosis, and allowing these cells to be eliminated in the bronchial mucus. These experiments indicate that should the coating be gradually removed by the lung fluids over long periods of time, subsequent dusting with aluminum powder should recoat and again inactivate the quartz particles. Observations are being continued on the animals remaining in the various experimental groups.

## THE INDUSTRIAL APPLICATION OF ALUMINUM

The practical application of metallic aluminum powder for the prevention of silicosis has been questioned by some, who claim that an explosive hazard would exist if aluminum dust were introduced into the atmosphere of a mine. The authors prior to the publication of their first paper were familiar with the work on the explosive properties of metallic aluminum powder done by Mason and Taylor,[10] of the Aluminum Company of America. These investigators demonstrated the fact that the minimum amount of aluminum powder required to produce an explosive mixture in air is 40 mg. per litre (40 ounces per 1,000 cu. ft.). They conducted further tests, using varying mixtures of silicious dust and aluminum powder to determine the explosive limits. They found that when two parts of silicious dust and one part of aluminum powder were used the mixture would barely ignite if blown through a flame. In the explosion chamber, using enough of this mixture to give five times the minimum explosion concentration of aluminium powder, no increase in pressure could be obtained on ignition. Obviously it would be impossible to produce an explosive mixture in a mine with any such quantities as would be required for our purpose.

Experimental work has been in progress at the McIntyre mine for some time to determine various methods of applying metallic aluminum powder for the prevention of silicosis. Certain methods have been devised whereby an excellent dispersion of the powder can be obtained in the underground atmosphere. By using small quantities of aluminum powder, varying from 3 to 20 grams, dispersed in a dust cloud, reductions in solubility of 90 per cent or better were obtained from dust samples taken 150 to 300 feet from the face, following a drift round blast, having a volume of 8,000 cu. ft. These investigations are still in progress and will be reported at a later date.

## CONCLUSIONS

1. Metallic aluminum on being converted into hydrated alumina reduces the toxicity of quartz in tissues in three ways, (*a*) by flocculation; (*b*) by adsorbing silica from solution; but (*c*) *chiefly* by coating the quartz particle with an insoluble and impermeable coating.

2. This coating has been definitely identified as a gelatinous hydrated alumina, which on drying forms the crystalline alpha aluminum monohydrate, Boehmite ($Al_2O_3.H_2O$).

3. The alpha monohydrate and trihydrate of aluminum have no effect on preventing silica from going into solution.

4. Other silicious materials when treated in a similar manner to quartz and aluminum in water appear to be coated by the precipitated gelatinous aluminum hydrate.

5. Under conditions as noted silicosis can be produced in experimental animals by exposure to quartz dust for five months.

6. No animals whose lungs on analysis contained 1 per cent or more of metallic aluminum have shown any evidence of silicosis up to periods of seventeen and a half months, in contrast to well developed silicosis in the quartz control rabbits in seven months.

7. In lungs having less than 1 per cent aluminum where fibrosis is present there is no demonstrable evidence of hydrated alumina in the fibrotic areas.

8. In lungs where the hydrated alumina is shown on staining to be intimately and uniformly mixed with the silica particles fibrosis has never been found.

9. Aluminum dust for the prevention of silicosis should be of a particle size below 5 microns and grease-free.

10. It should be uniformly mixed in any inhaled dust and bear a definite percentage to this dust at all times.

11. To prevent silicosis aluminum dust may be inhaled daily independently of the silicious dust.

12. The aluminum dust must be sufficiently concentrated in the inhaled dust to provide a minimum concentration in the lung of 1 per cent at all times.

13. The inhalation of aluminum dust in large quantities over long periods of time showed no effect on the general health of the animals and no evidence of toxicity or damage to tissues.

14. Aluminum dust in any concentration necessary to prevent silicosis has been shown to

be hundreds of times below the explosive concentration of aluminum powder.

It again affords us pleasure to record that the experimental work above described, which was conducted both at the Department of Medical Research and the McIntyre Mines was made possible by the continued interest of Mr. R. J. Ennis, General Manager of McIntyre Porcupine Mines Limited, and by the financial support of the same company, supplied on the recommendation of its President, Mr. J. P. Bickell. We wish to thank Sir Frederick Banting and members of the staff of the Department of Medical Research for the facilities and cooperation extended to us in checking our original findings. For the definite identification of the hydrated alumina coating on the quartz particles we thank most kindly Dr. Lester H. Germer and Mr. K. H. Storks of the Bell Telephone Laboratories, New York City. We would *particularly* express our appreciation for the cooperation so generously extended to us by Dr. Francis C. Frary, Director of the Aluminum Research Laboratories (Aluminum Company of America), and for supplying us with various forms of metallic aluminum and its compounds.

And finally we would record that same appreciation of the excellent work and dependable results provided through the efforts of Mr. F. Bremner, Chief Chemist of the McIntyre Porcupine Mines, and Mr. H. L. Collins (formerly of the Department of Medical Research), as well as of other members of the McIntyre staff.

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# THE CLINICAL SIGNIFICANCE OF A LUMP IN THE BREAST*

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THE title of this paper must conjure up at once the malignant lesion; but there are other swellings of the breast which are also of great moment, in that they may be, and frequently are, precancerous in nature. I refer to cystic nodulations and to papillary cyst-adenomata. There are of course, too, the chronic inflammatory swellings, tuberculous and luetic, but in the time at my disposal I cannot touch on these, other than to say that in a differential diagnosis the possibility of their existence should not be overlooked.

In any consideration of breast lesions 99 per cent of one's mental view is blackened out by the thought of cancer. I do not expect to add anything to your knowledge of this scourge, but, by emphasizing again the relation between benign and cancerous lesions of the breast, and by stressing once more the importance of vigilance, conscientious clinical examinations, early operation, and adequate histological search of all tissues removed, I venture to hope that some at least of my hearers may be stimulated to a determination to snatch more and more of these brands from the burning.

In 1846 Sir Benjamin Brodie[1] published a paper on benign cystic disease, and since that time there have been innumerable contributions to the subject. In 1883 Reclus[2] stressed two important features of the disease, the multiplicity of the cysts and the frequency of bilateral involvement. In 1892 Schimmelbusch's[3] paper on "Cyst-adenoma of the breast" appeared, embracing not only cystic disease but papilloma formation as well. In 1901 Paul[4] made the arresting statement, founded upon clinical experience, that the epithelial hyperplasia present in cystic lesions of the breast not infrequently terminated in carcinoma. Paul also said that, in his opinion, duct papilloma (or benign neoplasia, as it is now described) was but an advanced stage of simple epithelial hyperplasia, and further that this lesion was often the immediate precursor of cancer. So far as I know, Paul was the first to recognize the intimate relation between cystic lesions of the breast and malignant disease. Latterly Cheatle[5] has confirmed Paul's views on this subject; and since the appearance of Cheatle's text, "Tumours of the Breast", Ewing,[6] whose opinion is so universally accepted on this continent, has written:

> "I have been able to confirm these observations [of Cheatle] . . . It is . . . clear that chronic mastitis is a very important predisposing condition to mammary cancer. It appears, also, from the histological evidence, that many cancers arising in chronic mastitis do not represent wholly new processes, but, on the contrary, are the natural result of steadily increasing epithelial over-

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