CONTROL OF Silicosis IN VERMONT GRANITE INDUSTRY

PROGRESS REPORT

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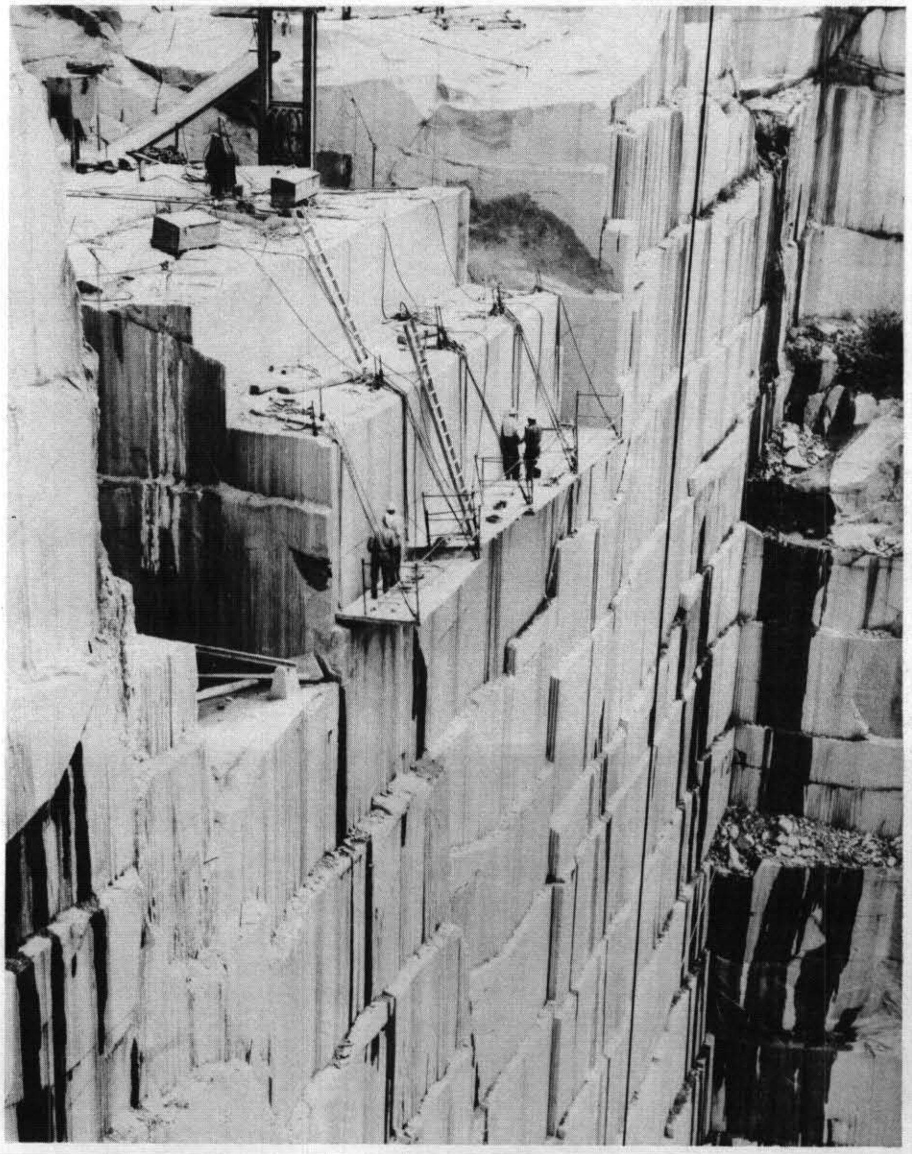

Figure 1.—*View of section of a Vermont granite quarry. This quarry covers over 40 acres and is over 300 feet deep. (Courtesy of Rock of Ages.)*

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Foreword

An extensive epidemiologic study of silicosis in the Vermont granite cutting sheds was made by the Public Health Service in 1924 as part of a broad investigation of diseases produced by dust. This silicosis study was the first in which it was possible to obtain a measure of the relation between the environment and the worker's physical condition.

In 1937 the Industrial Hygiene Division of the Vermont Department of Health instituted a silicosis control program based on an agreement between the granite shed operators and the labor unions. Dust control measures were initiated. The Vermont Department of Health periodically checked these measures and provided annual chest X-rays of the workers.

The stability of the worker population together with the continuing environmental and health measurements have made this group of great value in determining the effectiveness of preventive programs in silicosis. For these reasons in 1955 the Public Health Service restudied this group. This report demonstrates the great strides that can be made in the control of this disease by properly applied medical and engineering measures. It is hoped that these findings will accelerate the nationwide control of a disease which still represents a serious occupational hazard.

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Summary—Abstract

This report presents the results of investigations and observations on progress made to date in the control of silicosis in the Vermont granite industry. Silicosis was under investigation as early as 1920 because of the excessive death rate from tuberculosis among granite cutters.

The Public Health Service conducted an exhaustive environmental and clinical study in 1924–26 when it was possible for the first time to form some rough ideas of the limits of dustiness which may be regarded as reasonably safe from a health standpoint. At that time practically every pneumatic tool operator could be expected to develop the disease after 15 years of exposure to granite dust. The main factor in the rate of development of the condition was the presence of infection, which was almost always tuberculosis.

A reexamination of 116 men in 1937–38 by the Public Health Service confirmed the clinical findings of the earlier study. Environmental studies in the sheds by the newly established Industrial Hygiene Division in the Vermont Department of Health showed little, if any, improvement in the dustiness of the sheds up to that time. It was estimated that in 1937–38 at least 26 percent of the 2,100 workers in the Barre area sheds had either simple or complicated silicosis and another 15 percent had borderline silicosis.

The seriousness of the situation led to the tightening of the agreement between the granite manufacturers and the workers, and under the supervision of the Vermont Industrial Hygiene Division, dust control was stepped up. By 1939 all sheds had equipped dust-making operations with local exhaust ventilation. Since then, the Vermont Industrial Hygiene Division has been carrying out a program of routine investigations in sheds and quarries and taking periodic chest X-rays of workers. Manufacturers have also instituted a self-inspection program which has produced effective results.

An environmental resurvey of the granite industry in November 1955 showed that dust concentrations found were lower than those in previously published data, and confirmed the dust counts done recently by the Vermont Department of Health. Average counts were well within the Vermont limit of 10 million particles per cubic foot of air for this type of dust, and only 10 percent of the counts exceeded this limit.

The decrease in dustiness since the last published study in 1938 was caused by more effective exhaust ventilation. Not only is local exhaust ventilation available at all pneumatic tool operations, but excellent enforcement of regulations and cooperation of the manufacturers now keeps all exhaust ventilation equipment working efficiently. Newer processes such as wire saw and grinding machines add little, if any, to the dust load in the sheds. The dustiest operations at the present time are those performed with sledges or hammers, using no exhaust ventilation.

Settled dust samples averaged 21.9 percent quartz and 6.8 percent silicon carbide insoluble in hydrofluoric acid. This compares with with 29.1 percent quartz in the parent rock and 29.8 percent quartz in very old settled dust. Airborne dust averaged 24.9 percent quartz. The decrease in quartz content also reflects changes in processes over the past few years.

Toxic elements found by spectrographic analysis included lead, beryllium, and mercury, present at 1 percent, 0.1 percent, and 0.03 percent of their respective threshold limits.

Airborne dust had median particles averaging 1.0 micron. Although the particle size found is somewhat lower than in the past, this difference may be attributed to the efficiency of electron microscopy. The dustiness of the process is now so low that background smoke from the community masked the dust from stonecutting, and only through the use of the electron microscope was it possible to obtain a particle size distribution for the mineral dust.

By determining the total silica concentration in operators' breathing zones, it was found that stonecutters using dry processes were exposed to 1.4 milligrams per cubic meter as against 0.6 milligram for the other workers in the plant. These samples also revealed that the dust counts averaged 56 million particles per milligram of silicon dioxide at the above-mentioned dry processes. Total dust load from a group of samples taken over an extensive period averaged 1.5 milligrams per cubic meter. No method other than dust counting was shown to give consistent results.

Chest X-ray records that the Vermont Industrial Hygiene Division has been accumulating since 1937 were analyzed to determine the nature of progress in the suppression of silicosis. Annual prevalence rates among employed men appearing for X-rays have been steadily decreasing. In 1937–38, 45 percent of the men then X-rayed and working, had evidence of silicosis. The rate in 1952 was 20.3 percent and in 1956, 15.1 percent. The number of men with silicosis and still working in the sheds in 1956 totaled 244.

The inquiry into the nature of the silicosis problem was based on the cumulative records of 2,246 men who were X-rayed one or more times or were known to have died at some time during the 6-year period 1950–55. Of this number, 2,001 were employed in the sheds at the time of the last chest X-ray, 75 were either not working, or working at other trades, and appeared periodically for X-rays, and 170 were known dead. Silicosis in one stage or another was evident on the X-ray film in 535 of the study group.

The year 1937 was taken arbitrarily as separating precontrol and dust-control periods. A total of 1,112 in the study group gave histories as having started working in the granite industry before 1937, and 1,134 in 1937 or after.

Silicosis was diagnosed in 534 or 48 percent of the 1,112 men employed prior to 1937. The average number of years of employment for the men with silicosis was 32.4, and for the men with no silicosis, 26.3. At least two-thirds of the affected men had already worked 30 or more years. The average age of men with silicosis was found to be 59.3 years, and for those with no silicosis, 50.6 years. None of the men with silicosis was under 40 years; 110 affected men were 65 and over as contrasted with 40 men in the nonaffected group. It would appear from these figures that as the nonaffected group advances with age and length of employment, the chances are some will eventually have silicosis because of their previous dust exposure.

In the group of 1,134 men starting work in the granite industry in 1937 or later, or under dust-control conditions, one case of suspected silicosis was found. The average years of employment for this group was 7.4, and the average age was 35 years.

The analysis of the occupational experience shows that 73 percent of the 535 men with silicosis worked as pneumatic tool operators or at other dust-making jobs at some time or other. The other 27 percent of the cases was among men in occupations associated with potentially low exposures. This proportion was considerably in excess of that reported in earlier studies, suggesting that given a sufficiently long enough period of exposure at lower dust concentrations, silicosis will eventually develop.

Based on serial chest X-ray records of 153 men with a diagnosis of silicosis during the study period, it was determined that it took on the average 23 years of dust exposure to produce silicosis among pneumatic tool operators and 29 years among polishers, lumpers, and other low-dust occupations. For pneumatic tool cutters with silicosis and suspected tuberculosis, the average was 28 years, and for the other group 27 years. Although comparisons with previous years are not satisfactory, these findings suggest that the period for development of roentgenologic evidence of silicosis is longer than formerly.

Suspected tuberculosis in active, inactive, or activity undetermined, stages was diagnosed in 88 men or 22 percent of the 399 men with silicosis alive at the time of the last X-ray, and was a cause of 75 deaths, or 55 percent, of the 136 deceased cases. The average age of living men with silicosis and suspected tuberculosis was 56.2 years and average years of employment, 32.6. Corresponding averages for the deceased cases were 61.5 and 28.0 years.

Mortality data on granite workers were scanty, but indicated that silico-tuberculosis as a cause of death was decreasing in importance.

Although a lapse of 18 years is hardly long enough to judge the ultimate effect of current dust-control methods on the suppression of silicosis, the results of the 1955 environmental study and the analysis of chest X-ray records give cause for optimism. Further evaluations of the progress in controlling silicosis in the granite industry should be made about 1960 and again in 1965.

Introduction

Few industries in this country offer the opportunity to follow the epidemiologic pattern of an occupational disease as does the granite industry in Vermont. Silicosis and its association with increased susceptibility to tuberculosis was once the scourge of the granite cutter. Today, as a result of applying preventive techniques developed during many years of research and investigation into the problem, silicosis in the Vermont granite industry shows promise of gradually becoming a matter of history.

Twenty years have passed since the Vermont granite industry initiated dust-control measures, and the Vermont Department of Health instituted a silicosis control program. This program, carried out by the Industrial Hygiene Division with offices and laboratory at Barre, was based on the agreement between the granite manufacturers and labor unions to install dust-control equipment, and was extended to include periodic inspections of sheds and chest X-ray films of workers.

The routine inspections and chest X-rays have been continued over the years. Dust concentrations have been gradually reduced to below acceptable threshold limits. Insofar as the X-ray records show, only one worker appeared to have silicosis (classified as questionable) among the men starting work in the granite industry since the installation of dust-control equipment during 1937–39.

However, silicosis is still highly prevalent among men with exposures traceable to granite dust. Information was accumulated on 535 workers with silicosis who at sometime during 1950 through 1955 had X-ray evidence of the disease or who had died. In 1956, 244 workers with silicosis were still employed in the sheds. All but the one mentioned have had some exposure to silica dust in the predust-control days.

Years of concerted effort to make the industry safe are showing apparent dividends. However, less than 18 years have elapsed since the universal installation of dust-control equipment, and it is believed that this period is too short for determining whether silicosis can eventually develop under dust-control measures of today.

This progress report is presented to establish another baseline for future followup and evaluation of progress in preventing and control-

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ling silicosis in the Vermont granite industry. Part of the report is concerned with a review of developments in the industry and of earlier studies and investigations into the nature and extent of the silicosis problem. The major portion of the report, however, presents the results of an environmental study of granite sheds and quarries carried out in 1955, and a study of the extent and nature of the silicosis problem during 1950–55. The latter was based primarily on the analysis of X-ray examination records maintained by the Vermont Industrial Hygiene Division. Both were joint studies of the Occupational Health Program of the Public Health Service, and the Industrial Hygiene Division of the Vermont Department of Health.

What Is Silicosis?

Silicosis is a chronic disease of the lungs caused by breathing significant amounts of crystalline silica (quartz) in particulate form for prolonged periods of time. Silicosis is characterized anatomically by the development of small discrete nodules of fibrous tissue uniformly disseminated throughout both lungs. In its early stages, silicosis may produce no symptoms; in its later stages shortness of breath, decreased chest expansion, and lessened capacity for work, may be present, together with an increased susceptibility to tuberculosis (1).

A diagnosis of silicosis is usually based on a history of occupational exposure to free silica dust, a clinical examination of the worker and a characteristic appearance of chest roentgenograms. As a matter of convenience, it is divided into stages according to symptoms, physical signs, radiologic appearances and pathologic characteristics. In this report it was not practicable to make such distinctions, and as a result, silicosis is meant to include all stages, early, moderate, and advanced.

Silicosis occurs in uncomplicated form and with infection which is primarily tuberculosis. Simple silicosis seldom causes disability and the worker may continue at his work without much inconvenience until he is in the advanced stages of the disease. When silicosis is complicated by clinical tuberculosis the course of the disease is slow, but steadily progressive, causing total disability and often terminating in early death.

The principal factors in the causation of silicosis are:

1. *Composition of dust.*—The ability of dust to cause lung injury is dependent upon the content of silica in its free and chemically uncombined state—SiO_2 or silicon dioxide.

2. *Concentration and particle size of dust.*—For silicosis to develop, the worker must be exposed to relatively high atmospheric concentrations of fine dust. Atmospheric concentrations of silica dust below 5 million particles per cubic foot of air are rarely associated with the development of disabling silicosis. When the threshold tolerance is passed, the disease develops at a rate proportionate to the concentration of dust in the air and the percentage of free silica present in the dust. The particles must be in size ranges which gain access to the parenchyma of the lungs and are retained, usually about 5 microns or less in diameter.

3. *Duration of exposure.*—Silicosis normally requires years of exposure to silica dust before it can develop. The rapidity and extent of development are related directly to the number and size ranges of particles that enter the lungs and are retained.

4. *Individual susceptibility.*—This may be a factor in the development or progress of the disease because of structural or functional variations in individuals. Persons equally exposed do not necessarily develop the disease simultaneously or to the same degree, and some escape it altogether.

Silicosis is a preventable disease. Its prevention and control call for adequate medical and engineering measures. Medical control should include a practical program of preplacement and periodic examinations including chest X-rays, of workers exposed to silica dust. Engineering control may be accomplished by reducing the concentration of dust in the atmosphere through exhaust ventilation, isolation of dusty processes, wetting the dust at its source, and substitution of silica-free materials when practicable.

The Vermont Granite Industry

Vermont granite is composed of the following minerals: orthoclase, microcline, quartz, oglioclase, and biotite (essentially 66 percent feldspar, 26 percent quartz, and 8 percent mica). The percent chemical composition as reported by the Bureau of Mines (2) is:

	Percent
SiO_2 (total silica)	70. 0
Al_2O_3	15. 4
Fe_2O_3, FeO	2. 7
K_2O	4. 3
Na_2O	5. 4
CaO	1. 8

The principal health hazard is free silica or quartz which constitutes about 35 percent in the Barre granite.

Quarries

Early records from Vermont indicate that in 1814 several small concerns were engaged in removing stone from the hills and shaping it for use as underpinning, doorsteps, fence posts, hearthstones, manteltree pieces, tombstones, window tops and sills, as well as millstones. In 1824 three companies were producing "superior millstones" which, being highly durable, were much in demand in New England and Canada.

The granite industry in Vermont began commercially about 1830, with the opening of a quarry in the Barre area. In 1833 blocks of granite, quarried at Barre and transported by ox team to Montpelier at a delivered price of 20 cents per cubic foot, furnished the material for the building, as well as for the tremendous columns supporting the front portico of Vermont's State House.

Montpelier had been on a main line railroad since 1849, but it was not until 1875 that a branch line was extended to Barre, and 1889 that a line was built connecting the quarries on "Millstone Hill" with the city of Barre. These railroad extensions finally retired the old method of transport by multiple teams of horses or in some cases, oxen.

Easier movement of raw stock to cutting plant and finished product to market, contributed a great deal to the growth of this industry, which since the early part of the 20th century has made Vermont a leading granite producer in the United States.

In this period of development all the work was done by hand. Little dust was generated, and doubtless no one was concerned with possible silicosis among the artisans engaged in this trade. Steam-driven equipment gradually replaced the hand drills and sledge hammers used in quarrying and gave further impetus to the growing industry. Air-driven plug drills were introduced around 1900 and in 1905 compressed air was used wherever available.

The first jackhammer came into use in the quarries in 1919. In 1924 leyner drills with hand operated feed were developed and were used throughout the industry by 1928. The last steam-driven piston drill was replaced by a leyner in 1933. Motor or automatic feed was added to leyner drills in 1928 and in 1933 replaceable drill bits were introduced. This made it possible to drill holes continuously with the same set of drills for the entire depth of each hole simply by renewing drill bits. These new methods of quarrying granite increased production but also generated more dust.

Wire saws, using a water slurry of artificial abrasive, came into use in the quarries about 1948 and by 1952 were generally used throughout the industry. The most recent development in quarrying granite throughout the United States is the use of a flame drill, jet piercing or jet channeling technique. A mixture of fuel oil and oxygen upon ignition, and passage through a nozzle, produces a temperature of about 5,000° F. A stream of water surrounds the flame and the combined effect disintegrates the granite into fragments, which are blown from the channel being cut. This technique may replace many of the leyner and jackhammer drilling operations, thus reducing dust exposures where these operations are not controlled by wet techniques in other areas of the country; but at the same time it creates a greater noise problem. Recent sound level measurements made near this operation gave an overall level of 123 decibels (20 to 20,000 cycles per second) with 117 decibels in the 2,400 to 4,800 cycle frequency range. Similar octave band analysis of noise from a channel bar or leyner drill gave an overall level of 116 decibels but nearly equal levels over the frequency range of 75 to 4,800 cycles per second. One of the quarries in the Barre area is experimenting with this new type of equipment.

Sheds

Mechanization of operations in the granite sheds has progressed about as rapidly as in the quarries. A shift from all hand work to machines began in the late 1890's with the introduction of pneumatic tools, which varied in size from the small hand tool to the large surfacing machines that had the pneumatic head supported on a movable radial arm. Their use increased production immensely but was accompanied by a tremendous increase in dust generation which resulted in a high incidence of silicosis and excessive mortality from tuberculosis for granite cutters. Pneumatic tools are still in use today with little changes in design; the amount of dust generated is perhaps as great as it was in 1900, but is now controlled by improved local exhaust ventilation.

Gang saws were introduced in the sheds about 1915. They replaced many of the hand and pneumatic cutting operations and thus reduced the amount of dust because they were operated with water and an abrasive. Large surfacing machines were also gradually replaced by the gang saws thus reducing further the dust generated. Sandblasting was introduced in the early 1920's for lettering and carving monuments and markers. The abrasive used at first was silica sand; but silicon carbide and aluminum oxide came into general use in the early thirties. Further developments included the introduction in the late thirties of high speed carborundum saws and planes, operated wet. The wire saw, which came into general use in the sheds about 1952, reduced the amount of finishing formerly required. A stream of water and abrasive fed onto the wire rapidly cuts granite without producing dust and with very little noise.

Employment

Mechanization of quarry and granite shed operations and a fluctuating market over the years have influenced the number of persons employed and types of operations engaged in. In 1894, for example, 72 quarries were operating in Vermont. This number was gradually reduced until 1938 when only five major quarries were in operation—all located in the Barre district (3). The number has remained fairly constant during the past 20 years with five still in operation in 1956.

Employment, too, has fluctuated during the past years. In 1920 the industry employed about 3,500 men, of whom 1,500 to 2,500 were cutters (4). Urban (5) reported in 1937 that there were 115 granite cutting and finishing sheds operating in the State with 2,350 employees [1] and about 700 employees in the five granite quarries (1938). In 1956, five quarries employing about 600 workers and about 100 sheds with an average of 1,700 to 1,800 workers were operating in the Barre area (fig. 2). Thus, in the past 20 years there has been a reduction of about 500 workers in the granite industry. This reduction has been due in great part to mechanization of the operations, and to some extent, to changes in consumer demand for granite products.

[1] In the Barre area, there were about 100 sheds with 2,100 workers at that time.

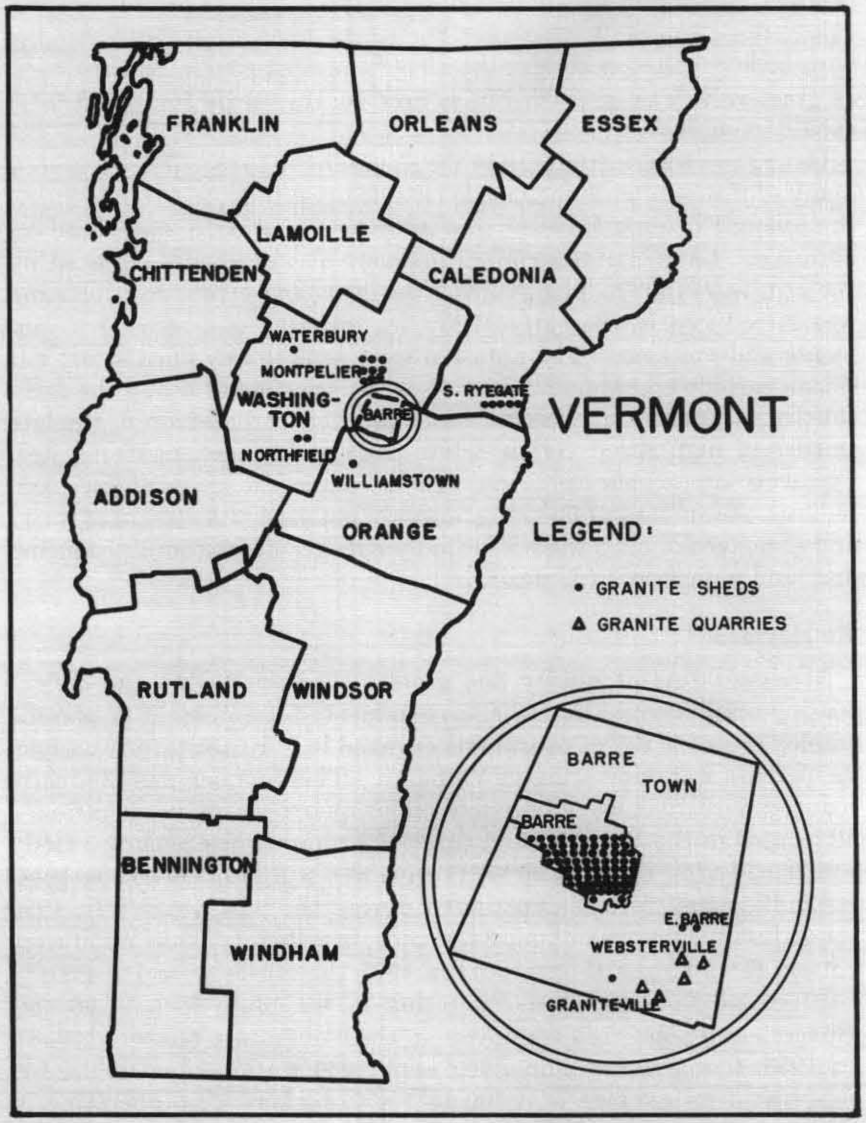

FIGURE 2. *Location of granite quarries and sheds operating in 1956.*

Some idea of the impact of mechanization over the years on the proportion of men employed in various occupations in the sheds may be obtained from table 1. The distribution of occupations is based on data from previous studies and chest X-ray records and is approximate. For instance, the proportion of pneumatic-tool operators, carvers, letterers, and cutters decreased from 62 percent in 1926 to

37 percent in 1938; in 1955 these operations accounted for only 29 percent of the shed employees, despite a large influx of apprentice cutters. On the other hand, the number of sandblast operators as well as of sawyers increased from 1 to 9 percent over the same period with corresponding increases in all other occupations except tool grinders, derrickmen, blacksmiths, and surface-machine operators.

TABLE 1. *Comparative distribution of occupations of granite shed workers based on data from previous studies and chest X-ray records* [1]

Occupation	Source of data					
	1924–26 study		1937–38 survey of sheds		Records of men X-rayed in 1954–55	
	Number	Percent	Number	Percent	Number	Percent
Number of sheds	14		115		[2] 100	
Number of workers	972	100	2,112	100	1,494	100
Pneumatic tool operators, carvers, letterers, cutters	600	62	783	37	429	29
Surface machine operators	70	7	230	11	43	3
Tool grinders	33	4	89	4	27	2
Lathe operators			5	(3)	4	(3)
Sandblast operators	7	1	162	8	137	9
Polishers, bed setters	51	5	217	10	218	14
Sawyers	10	1	97	5	141	9
Lumpers	71	7	151	7	151	10
Derrickmen, cranemen, boxers	42	4	171	8	158	11
Blacksmiths	10	1	75	4	9	1
Foremen, engineers, mechanics, machinists, maintenance, laborers	78	8	132	6	177	12

[1] Figures exclude draftsmen and office workers.
[2] Estimated.
[3] Less than 0.5 percent.

In spite of these changes, according to U. S. Bureau of Mines (6), Vermont has led all States both in quantity and value of memorial granite sold, except in 1952, when because of a 5-month strike, it fell to second place in quantity. The granite is noted for its durability and fineness of grain and is used extensively for memorials (2).

Another change not reflected in the table is the growing trend toward the use of small surfacing machines. For instance, in 47 sheds which have operated continuously over a period of 16 years, the number of large surfacing machines dropped from 64 in 1940 to 3 in 1956; medium surfacers dropped from 60 to 23; and baby surfacers increased from 14 in 1940 to 157 in 1956.

Early Studies of Silicosis in the Vermont Granite Industry

The earliest suspicion of unhealthy effects of breathing granite dust arose from the rapidly increasing tuberculosis mortality among granite cutters at a time when a campaign led by the National Tuberculosis Association was bringing tuberculosis from first down to seventh place as a leading cause of death in the United States registration area (4). Physicians in the Barre area were long familiar with a lung condition which they took for granted as inevitable in granite cutters, and which they diagnosed as tuberculosis or possibly stonecutter's phthisis. It was observed, however, that the disease had certain peculiarities that distinguished it from ordinary tuberculosis infection, and gradually it was identified with the silica hazard.

Dr. D. C. Jarvis, a Barre physician, succeeded in 1920 in interesting the Trudeau Sanatorium at Saranac Lake, N. Y., in the situation. A "Committee on Mortality from Tuberculosis in Dusty Trades" was set up with Dr. F. L. Hoffman as its chairman and through its efforts, 427 Barre granite cutters were examined clinically and radiographically. All but 28 were found to have had either definite or probable silicosis and tuberculosis, or uncomplicated silicosis. The average length of exposure to dust in the silicosis cases was about 21 years. Experimental research, augmenting this study and ca ried out by Dr. L. U. Gardner at the Saranac laboratory showed that it was impossible to reproduce silicotic nodulation in normal guinea pigs by 2 years' exposure to granite dust.

Dr. Hoffman's report on mortality statistics of granite workers, which came out in 1922 (7) and included the Vermont industry, further established that mortality from tuberculosis was associated with degree of dust exposure, and that it was highest in granite cutters using pneumatic hand tools. For instance, in 1917 the pulmonary tuberculosis death rate among granite cutters was 1,095.5 per 100,000 as contrasted with 96.4 for the total adult population of the State.

1924–26 Study

In 1924–26, the U. S. Public Health Service made its comprehensive study of the effect of dust on the health of granite workers (8), in which the worker's physical condition was correlated with his environment. By this time, methods of air sampling, counting and measuring particle size of dusts had been standardized, permitting a comparison between dust hazards in different processes. On the basis of this study, it was possible to form some rough ideas of the limits of dustiness which may be regarded as reasonably safe from a health standpoint. It also established further fundamental facts on the etiology of silicosis in the granite industry which remain materially unchanged today and which form a basis for a preventive program.

Fourteen granite sheds employing 972 men were studied. The average dust concentration at all operations was 37.2 million particles per cubic foot of air. Average dust concentrations at individual operations ranged from 59.2 million particles per cubic foot of air for pneumatic hand-tool operators, 44.0 for surface cutters, 37.0 for carvers and letterers, to 20.2 for general room air. Some counts were as high as 200 million particles per cubic foot of air. The only dust control measures consisted of local exhaust systems on a few of the surfacing machines. The dust concentrations on the equipped machines averaged 12 million particles per cubic foot of air.

Of 972 granite workers examined, 614 were pneumatic hand-tool operators and 104 were surface machine operators, carvers, letterers, and tool grinders. The first case of early silicosis in these two groups appeared after approximately 2 years of service; the prevalence was 100 percent after 15 years of service. Tuberculosis became manifest usually after 20 years of service, rising consistently with length of service, and terminating fatally within a short time after onset.

A third group of 146 persons was exposed to average plant dustiness of 20 million particles per cubic foot of air, and another group of 108 men was in occupations where the dustiness averaged between 3 million and 9 million particles. The development of silicosis in these groups was proportionate to the dust exposure. In the lowest exposure group, two cases of early silicosis occurred after 10 years' exposure, and one case of moderately developed silicosis after 6 years' exposure.

On the basis of these findings it was concluded that for this type of work a presumptive safe limit of dustiness for rock dust containing 35 percent of free silica lay somewhere between 9 million and 20 million particles per cubic foot of air in the size range under 10 microns. Among other significant findings were the following:

(1) The long period of service before the liability to tuberculosis became manifest, generally 20 years or more.

(2) The sharp correlation between the length of exposure to the dust and the prevalence of tuberculosis, and also the death rate from this disease.

(3) The close correlation between the extent of dust exposure and the health of the worker.

(4) The universal occurrence of silicosis among the workers exposed to concentrations above 40 million particles per cubic foot of air.
(5) The large proportion of workers who finally succumbed to tuberculosis.
(6) The almost invariably fatal form of the disease (silicosis) within a short time after the onset.

1937–38 Restudy

In 1937–38, 116 of the men studied in 1924–26 were reexamined by the U. S. Public Health Service, confirming the findings of the original study (9). Although the dust exposure was judged about the same, the followup study indicated clearly that the presence of infection, which was almost invariably tuberculosis, was the main difference in the rate of development of the condition. The progression was marked in the highly exposed cutters in contrast with workers exposed to lower concentrations of dust.

Russell further stated in the report that, "But one would hesitate to be positive that no harm would come to persons working for many years under a concentration of 20 million particles per cubic foot."

Silicosis in Granite Quarries

Bloomfield and Dreessen (10) conducted an environmental and medical study in 1931 in a representative quarry in the Barre area, employing 150 men. A summary of the environmental results is shown in the following table:

Occupation	Number of workers	Dust concentration (million particles per cubic foot)		
		Average [1]	Minimum	Maximum
Leyner drillers	17	144.4	5.3	1,085
Plug and jack hammer drillers	37	112.0	4.1	396.8
Plug yard drillers		36.9	5.3	58.0
All other workers	88	5.8	4.1	10.7

[1] Weighted exposures.

The airborne dust contained 35.2 percent quartz with a median particle size of 1.5 microns.

Medical examinations were made on 63 men of whom 36 were drillers. Silicosis was found only among the drillers. Half of the men who worked less than 5 years were not affected. Six of the 18 men who had worked 5 to 19 years, and 4 out of 5 who had worked 20 years or more, had silicosis. The authors stated: "It is apparent from the results of our present dust study on granite quarries that 38 percent of the men employed are exposed to quantities of granite dust which would be expected to lead to definite lung injury." This study was made before dust control measures were used in the quarries.

Prevalence of Silicosis in 1937–38

In 1937–38, Dr. L. E. Judd (11), then associated with the Office of Industrial Hygiene of the Vermont Department of Health, examined clinically and radiographically 850 men who appeared voluntarily. By projecting his findings to the 2,100 granite shed workers then employed in the Barre area, he estimated that there were some 235 men with silicosis and 320 others with silicosis and probable or positive infection, usually tuberculosis, or a prevalence rate of 26 percent. Another 16 percent were borderline cases in whom the condition could progress to definite silicosis. He further estimated that of some 300 unemployed and disabled cutters, between 100 and 150 were suffering from tuberculosis.

Dr. Judd reported the results of these studies in 1939 at the Fourth Saranac Laboratory Symposium on Silicosis and forecast observations which typify the situation today. He said:

> The results of dust control on health of these workers cannot be measured positively for several years with any accuracy; however, it is my belief that with adequate dust control:
>
> 1. No new cases of silicosis will develop after 2 or 3 years.
> 2. Silicosis cases will not progress markedly unless infection intervenes.
> 3. Patients with silicosis and possible infection, who continue to work, will run a longer course than formerly.

Developments in Engineering Control of Granite Dust

Efforts to control dust in the granite sheds were made as early as 1914 when exhaust systems were installed on a few surfacing machines. These early exhaust systems did not include dust collectors but consisted merely of fans to remove the dust from the operator's breathing zone (figs. 3 and 4).

Beginning with 1922, probably as a result of the inquiries into the high mortality from tuberculosis among granite cutters, the Barre manufacturers and Barre Branch Granite Cutters International

FIGURE 3. *Attempts at controlling dust in granite sheds consisted of exhaust fans located in windows or openings in the sheds. Picture shows exhaust from sandblast discharging dust into outside air. Dust exhausted in this way could easily reenter the shed. (About 1925.)*

Association wrote into their annual agreements specific clauses regarding dust control. This agreement required, among other preventive techniques then known for suppression of dust, that "all dust creating machines must be adequately equipped with dust removing devices when proven practical * * *." It also provided for the creation of a 6-man health committee whose duties were to investigate, to assist in the development, the perfecting and the introduction of dust removing devices; to consider insurance against sickness and improve in every possible way general working conditions. The dust control clauses were continued in each year's successive agreement until 1937 when a supplemental agreement was drawn up, requiring the installation of dust removal systems in every shed before September 1, 1937 (later extended). Insofar as it could be learned, the joint committee was eventually replaced by separate safety committees which function today.

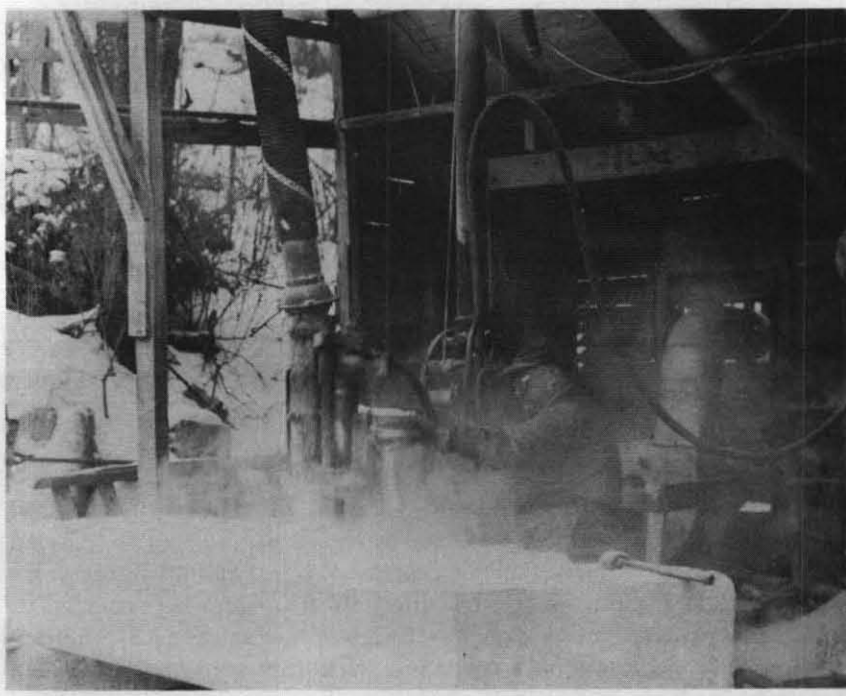

FIGURE 4. *Early type of local exhaust for surfacing machine in an open shed. From the amount of visible dust the local exhaust was either not in operation or not effective. A large blower, in background, was not connected to exhaust ducts and was apparently used to remove dust from the general work area. (About 1936.)*

In the meantime, the problem of exhausting dust in granite sheds was being pursued continuously by various researchers. In 1928, Bloomfield (12) studied the efficiency of dust-removal systems in two granite sheds. He found that if maintained and used properly, exhaust ventilation systems would reduce most dust exposures to an average level of below 20 million particles per cubic foot of air. Average dust concentrations (millions of particles per cubic foot) in the two plants studied as compared with those in the 1924–26 study (winter counts) were:

Operation	Without efficient local exhaust systems	With efficient local exhaust systems	
		Plant X	Plant Y
Pneumatic hand tool	55.2	23.5	9.5
Surface cutting	45.0	15.3	10.6
Tool grinding	30.0	5.0	12.1
General air	22.6	5.6	8.9

In 1930, Hatch, Drinker, and Choate (13) published the results of a laboratory study on the efficiency of dust-control systems for pneumatic granite cutting tools. They provided a rational basis for design of control systems to reduce dust concentrations to a safe level. By 1930, so-called dust collectors were installed in several plants; these were not the type in general use today but consisted primarily of settling chambers as illustrated in figure 5. More efficient dust collectors were first installed in 1934 on surfacing machines and, over the next few years, other operations were gradually controlled (fig. 6).

Industrywide control of all dust producing operations had its beginning in the latter part of 1937. Earlier that year, Urban (5) who became associated with the newly established Office of Industrial Hygiene of the Vermont State Department of Public Health, carried out an engineering survey in 35 representative cutting plants. He found that dust conditions were essentially the same as reported in 1925. In 1938 he studied a group of plants, operating with complete dust control, installed in accordance with the agreement between granite manufacturers and the union. The introduction of local exhaust devices reduced the dust count for dust-making occupations to less than 20 million particles per cubic foot of air and the general plant atmosphere to approximately 5 million particles per cubic foot of air (fig. 7). He observed, however, that the mere installation of dust-control equipment was not sufficient to eliminate hazardous dust concentrations. Some high counts encountered were due to neglect in maintaining the exhaust equipment in good condition or to lack of cooperation of workers using the equipment.

Year-round wet drilling was introduced in the quarries and plug yards in 1950 and was universally used by 1953 (figs. 8, 9, and 10). Prior to this time, attempts were made to control the dust from jackhammers, plug and leyner drills with local exhaust ventilation, but none of the several arrangements proved successful (figs. 11, 12, and 13). Consequently, these drills were usually operated without benefit of dust control until 1950.

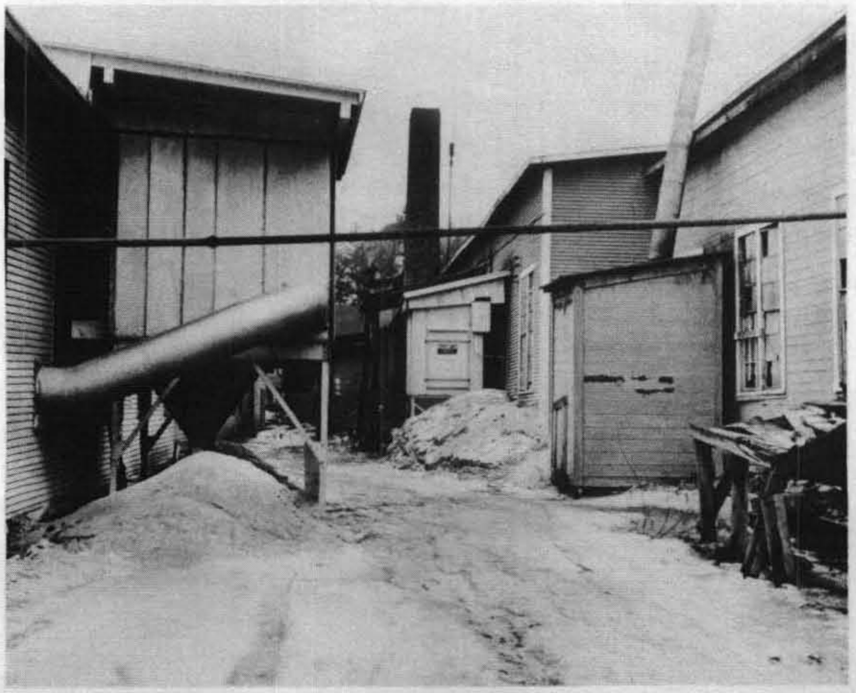

FIGURE 5. *Early attempts to collect the dust generated from granite cutting operations in sheds. To the right is a settling chamber with high stack to prevent dust from re-entering the shed. To the left is a more modern cloth bag dust collector. Prior to 1948, air discharged from the collector was recirculated in most sheds. (About 1937.)*

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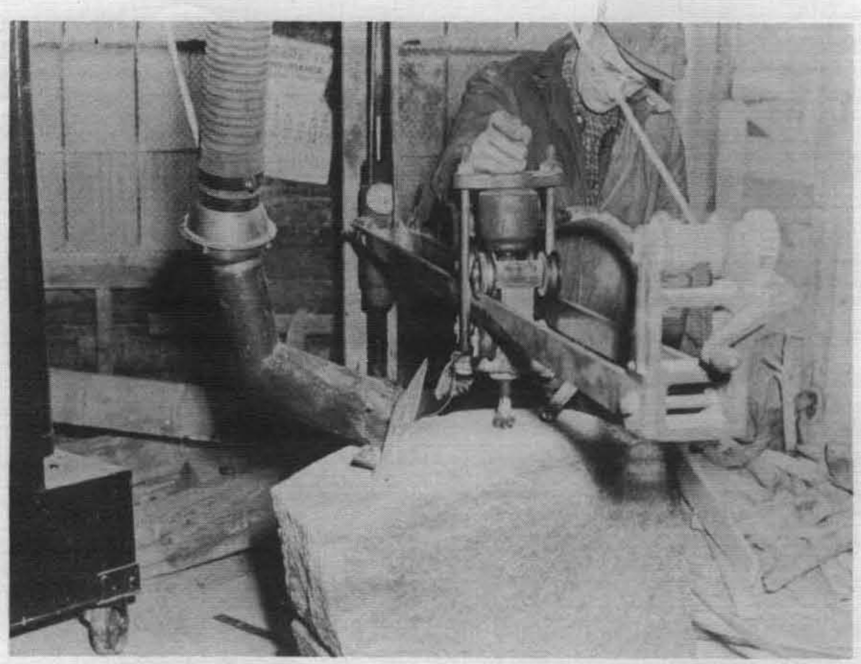

FIGURE 6. *This picture, taken in 1936, shows that dust from a baby surfacer can be effectively controlled by local exhaust ventilation. However, the hood is only effective when used close to the bit.*

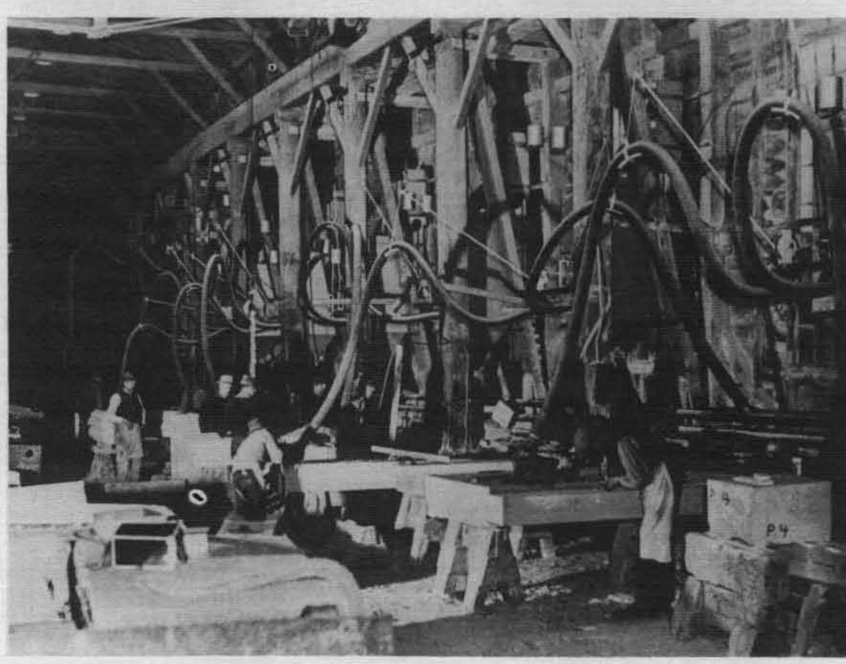

FIGURE 7. *Interior view of a granite shed showing individual dust collectors attached to flexible hoses and exhaust hoods. (About 1937.) These units were gradually replaced by one or more larger central dust collectors.*

FIGURE 8. *Modern wet drilling with jackhammer in plug yard. Rubber cup prevents spraying operator with water. (Courtesy of Rock of Ages.)*

FIGURE 9. *Closeup view of leyner bar drilling as practiced since about 1950. Note absence of visible dust as a result of using wet methods.*

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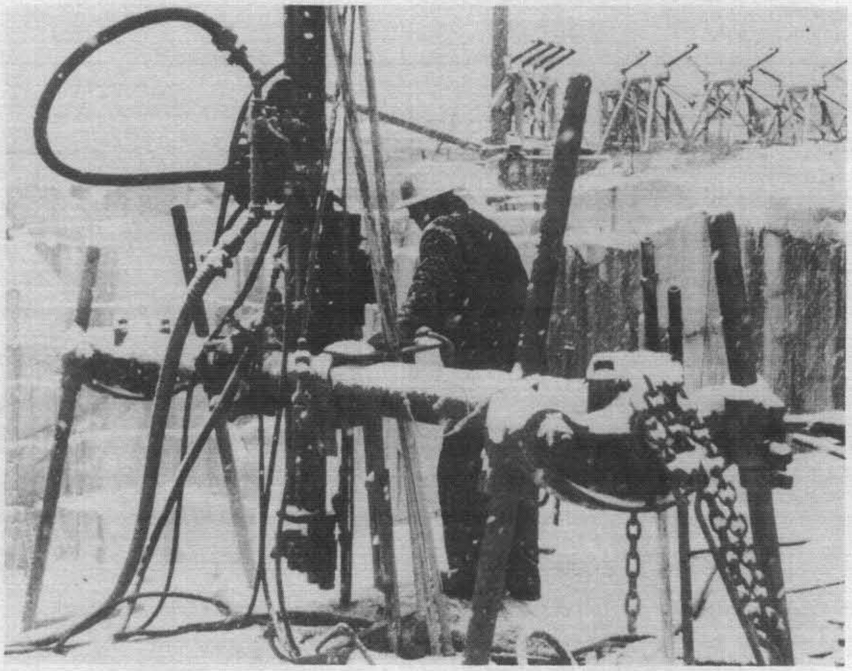


FIGURE 10. *Wet drilling with leyner in winter. Heated water is being used. (1955.)*

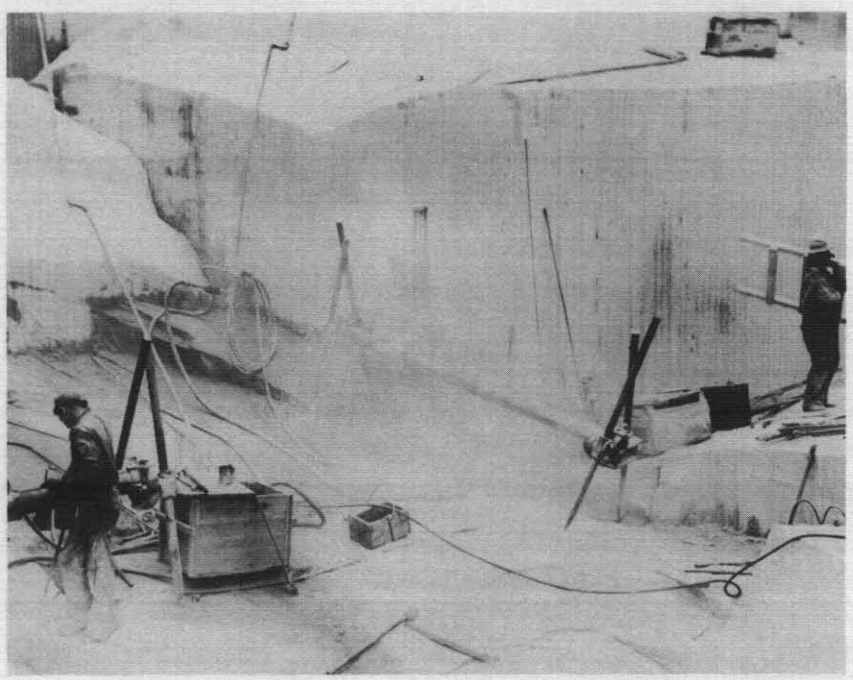


FIGURE 11. *Leyner bar drilling without dust control. Operator in background is barely visible through dust cloud. (About 1936.)*

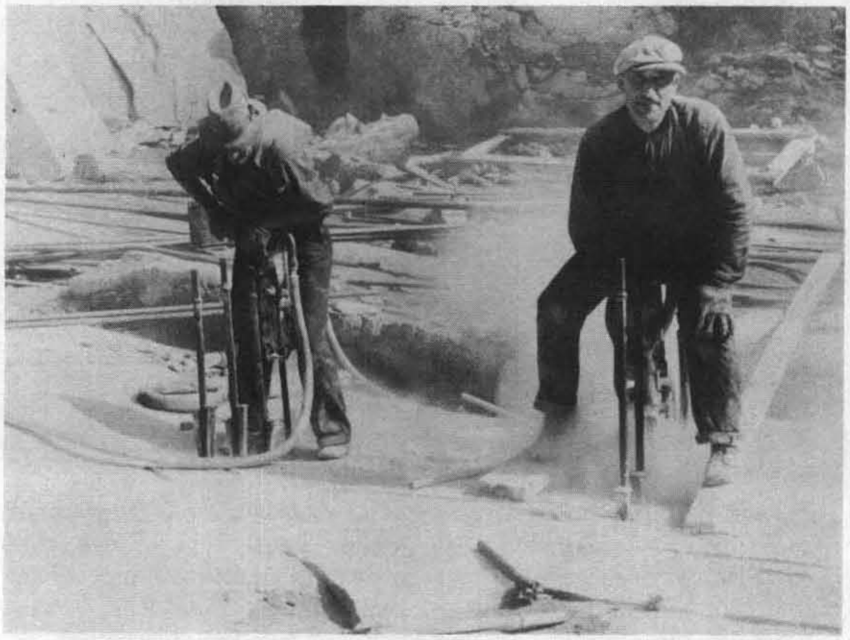


FIGURE 12. *Jackhammer drilling without dust control. (About 1936.)*

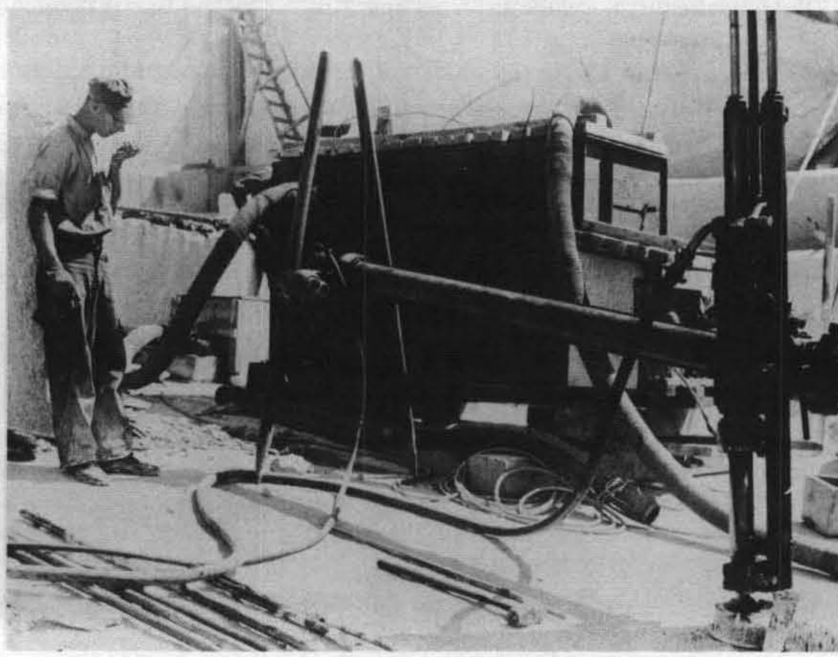


FIGURE 13. *One of the several types of local exhaust systems for controlling dust in the quarries about 1937. Note collar around drill at lower right and flexible hose. None of these early exhaust systems proved successful and as a consequence drilling was usually done without benefit of dust control until about 1950.*

Present Silicosis Control Program

Since its establishment in 1937, the Industrial Hygiene Division of the Vermont Department of Health has maintained a close supervision over dust control in the granite industry as well as in other dusty trades, and has been conducting a continuous program of X-ray examinations for workers in the dusty trades.

Engineering Control

Former high dust concentrations in the sheds have been gradually reduced by wet methods, local exhaust ventilation of dry stone cutting, and enclosure with local exhaust for abrasive blasting. There still remain, of course, a few workers who use their local exhaust equipment improperly and unnecessarily expose themselves and neighbors to high dust concentrations.

With dust control available for all operations, the Industrial Hygiene Division is stressing maintenance of the units, with improvement where necessary. Based on the quantities of exhaust ventilation necessary for dust control of the various operations, a rating system was set up as follows:

Airflow standards (cubic feet per minute)

Rating	Large surfacer	Medium surfacer	Baby surfacer and bankers
Good	800 or more	600 or more	400 or more.
Fair	720 to 800	540 to 600	360 to 400.
Poor	Less than 720	Less than 540	Less than 360.

A "fair" rating, which is within 10 percent of the design value, is considered acceptable, although an increase in the airflow may be suggested. Ratings of "poor" require immediate attention. Abrasive blasting booths are rated on face velocity through the curtain opening.

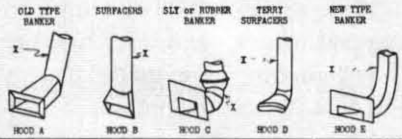
Standardized types of hoods are generally used throughout the industry, so it has been possible to set up a convenient table of static suction versus airflow for each type and size of hood. The method simplifies measurement so that only a pocket vacuum gage and a card as pictured below are required to check a complete exhaust ventilation system.

FRONT

DIVISION OF INDUSTRIAL HYGIENE
VERMONT DEPARTMENT OF HEALTH
Barre City Hospital
Barre, Vt. Tel. 582

GAGE READING inches water	AIR FLOWS cubic feet per minute				GAGE READING inches water
	Hood E X = 3½" square	Hood A X = 3½" dia.	Hood A & Hood B X = 4" dia.	Hood B X = 4½" dia.	
1.0	329	228	295	375	1.0
1.2	360	248	322	411	1.2
1.4	393	269	350	444	1.4
1.6	415	287	373	474	1.6
1.8	441	304	395	504	1.8
2.0	465	321	416	530	2.0
2.2	490	338	440	556	2.2
2.4	511	352	457	581	2.4
2.6	535	368	478	605	2.6
2.8	551	380	494	628	2.8
3.0	570	393	510	649	3.0
3.2	588	405	526	671	3.2
3.4	610	420	543	692	3.4
3.6	625	431	560	712	3.6
3.8	640	442	574	730	3.8
4.0	660	455	591	750	4.0
4.2	675	465	604	768	4.2
4.4	690	475	618	786	4.4
4.6	706	486	632	804	4.6
4.8	720	496	645	822	4.8
5.0	736	508	660	838	5.0

BACK



GAGE READING inches water	AIR FLOWS cubic feet per minute				GAGE READING inches water
	Hood D X = 2½" dia.	Hood D X = 3" dia.	Hood C X = 4" dia.	Hood E X = 5" dia.	
3.0	142	204	265	464	1.0
3.4	151	218	290	507	1.2
3.8	159	230	314	546	1.4
4.2	167	242	334	585	1.6
4.6	175	253	355	620	1.8
5.0	183	264	374	654	2.0
5.4	190	274	392	690	2.2
5.8	197	284	410	720	2.4
6.2	204	294	426	750	2.6
6.6	210	303	443	775	2.8
7.0	216	312	458	801	3.0
7.4	223	321	473	830	3.2
7.8	229	330	488	855	3.4
8.2	234	338	502	880	3.6
8.6	240	346	516	904	3.8
9.0	246	354	530	928	4.0
9.4	251	362	543	950	4.2
9.8	256	370	555	970	4.4
10.2	261	377	568	993	4.6
10.6	266	384	580	1015	4.8
11.0	271	391	592	1040	5.0

The Industrial Hygiene Division has made periodic inspections of the granite sheds since 1940, measuring the airflow at each exhaust unit and rating it as "good," "fair," or "poor." Records of these inspections, now made twice a year, are complete since their inception. The records show an increasing percentage of "good" ratings, particularly in the past 5 years; "poor" ratings during the past 3 years have been rare.

To further reduce dust exposures, the Barre Granite Manufacturers Association has sponsored a self-inspection program. Under this program, member manufacturers measure the airflow at each of their own units monthly, and send in a report to the association. This program is promoting better maintenance and use of the exhaust ventilation systems.

Other control activities of the division have included the requirement that all dusty operations must be exhausted through approved dust collectors. In 1948 recirculation of air from dust collectors was prohibited by a regulation passed by the State Department of Health. Efficiency of the control systems is spot-checked from time to time by dust counts.

Medical Control

The medical phase of the State's silicosis program consists of periodic chest X-ray examinations of workers in the dusty trades. X-rays are taken on 14-inch by 17-inch film by the Industrial Hygiene Division staff and are read by its medical consultants. From 1938 to 1950 the division held evening clinics at its Barre office. Participation was voluntary, and the number X-rayed varied. Later in 1950, arrangements were made with various manufacturers to set up a portable X-ray machine in the sheds and take X-rays during working hours. This resulted in more than doubling the number of men X-rayed, but still only about one-half of the men on the payrolls were availing themselves of the service.

In 1951, the General Assembly passed the Vermont Occupational Disease Law (14) which included compensation for silicosis. Among the requirements of the law is that employees exposed to the hazards of silicosis or asbestosis be X-rayed by the Industrial Hygiene Division when so requested by the employer. The granite manufacturers, however, entered into a mutual agreement with the employees whereby men would continue to present themselves voluntarily for X-rays as in the past.

FIGURE 14. *Trailer unit for taking periodic chest X-rays of workers at sheds and quarries parked near a shed. (1956.)*

To meet an anticipated increased load, the Industrial Hygiene Division acquired a house trailer shell, converted it into a mobile X-ray unit and put it into operation in September 1951 (fig. 14). As a result, the X-ray program was speeded up considerably, and the number of workers X-rayed was increased further. For instance, in 1950, 937 workers were X-rayed; from 1952 to 1956 the number reached was between 1,353 and 1,453. Since 1937, the division has taken 13,795 X-ray pictures of granite workers alone. The number X-rayed annually over the past 20 years is shown in table 2.

TABLE 2. *Number of granite workers X-rayed annually by the Vermont Department of Health, 1937–1956*

Year	Number of workers X-rayed		
	First time	Rechecks	Total
1937	645	0	645
1938	160	211	371
1939	89	169	258
1940	90	155	245
1941	137	308	445
1942	83	251	334
1943	86	212	298
1944	38	183	221
1945	37	248	285
1946	109	235	344
1947	62	325	387
1948	203	452	655
1949	36	320	356
1950	239	698	937
1951	475	519	994
1952	209	1,178	1,387
1953	191	1,262	1,453
1954	131	1,306	1,437
1955	51	1,302	1,353
1956	96	1,294	1,390
Total	3,167	10,628	13,795

The Industrial Hygiene Division maintains an individual record on each person appearing for X-ray examination. Noted on the form are items such as case number, name, address and age of worker, employment history, name and address of personal physician, periodic film readings, diagnosis, and a few other personal and medical facts ascertained from time to time. X-ray films are identified by case number and filed so as to be conveniently available for comparative readings. Serial films are available on most of the men, some going as far back as 1937 and 1938.

Because of lack of medical staff and the opinion of local physicians that clinical examinations in uncomplicated silicosis are seldom of value, physical examinations of the men are not part of the program.

Workers with suspicious findings are referred to their own physicians for examination. In the early years of the program, symptoms were ascertained and noted, but as workers seldom admitted any, this practice was eventually discontinued. The staff consultants base their diagnosis of silicosis on the appearance of X-ray films and occupational history of exposure to silica dust. Findings suggestive of tuberculosis or complicating infection are so reported. Further study of suspected infection is left to the individual's personal physician.

Results of chest X-rays taken are reported routinely to the workers and their personal physicians. The report to the physician contains detailed interpretation of the film and diagnosis arrived at. Reports to workers vary, depending upon the film findings.

Workers with negative lung findings receive a card stating:

> Readings of chest X-rays taken by this division are sent to the doctor designated by the individual as his family physician.
>
> The report of your X-ray was satisfactory.

Workers with positive lung findings but with no change since the last X-ray are sent a card which reads:

> Readings of chest X-rays taken by this division are sent to the doctor designated by the individual as his family physician.
>
> Your recent X-ray shows no change over the last one taken by this division. If you desire any further information, consult your physician.

Workers with positive lung findings or changes observed for the first time are sent the following form requesting them to see their physician:

> Name --
> Kindly visit or call --
> For the report of your chest X-ray taken----------------------------
> ---

Environmental Study—1955

Background

A cooperative environmental study was conducted in November 1955, by the Industrial Hygiene Division, Vermont State Department of Health, and the U. S. Public Health Service, in 20 sheds, 2 quarries, and a plug yard.

One of the objectives of the study was to obtain comprehensive data on dust concentrations at the different occupations, for which partial data had been collected by the State. Another, and perhaps more important, objective was to determine the particle-size distribution and chemical characteristics of the dust.

Information on particle size, past or present, was scanty at best, and that on the proportion of particles too small to be resolved by light field microscopy, completely unavailable. This latter was considered particularly important because it was the impression of some individuals that the newer granite cutting and finishing methods (for example, wire saw and contour grinding) had introduced large numbers of very fine particles, which would not be counted by the usual light field technique, nor entirely collected by the Greenburg-Smith or midget impinger.

By collecting the dust on molecular filters and determining the size by electron microscope, techniques unavailable to previous investigators, it was possible to obtain complete particle size distribution measurements for the study.

Since more nearly complete data on the chemical and mineralogical composition of the dust were also desired, airborne dust was analyzed for quartz by X-ray diffraction, for total silica by a colorimetric method, and for trace elements by emission spectrograph. These methods had not been employed in the previous studies of the Vermont granite industry.

Operations

In the Barre district there are five quarries, all of which operate the year round. They annually produce a total of approximately a million cubic feet of usable granite, and in addition remove four times this quantity of waste or "grout."

Blocks of granite, which may weigh 25 tons, are produced by ringing the perimeter with a line of vertical holes, drilling out the cores between these holes, then exploding charges of black powder in horizontal "lift holes" which have been drilled at the bottom. The vertical holes are made by a leyner, a heavy pneumatic drill which rides above the line of holes on a channel bar (figs. 9 and 10). The leyner drills, and in fact all the drills used in quarries and plug yards, are operated wet throughout the year, using heated water in the winter. Wire saws and flame drills are also used, and replace the leyners in some quarrying operations. Wire saws and flame drills use water in the process of cutting stone.

Approximately 80 percent of the granite removed is finished locally. Some of this is taken by flatcar to a plug yard to be cut into smaller dimensions. In a plug yard holes are drilled with a jackhammer to a depth of a few inches at intervals along a chalk line (fig. 8). The stone is then split by pounding steel wedges into the holes. As in the quarries, the drilling is done wet, except that the holes are started dry. Dust exposure in the plug yards occurs principally during the very brief period while the hole is being started.

With the exception of a new plant not in operation at the time of the study, the granite-cutting sheds differ little from those in existence many years ago. They are long, narrow frame buildings with dirt floors as shown in figure 15. Figure 16 shows a representative floor plan. Operations carried on in most of the sheds include polishing, wire sawing, surfacing, pneumatic hand tool cutting, hammer and hand tool cutting, contour grinding, and sandblasting.

Polishing is done by placing the granite slabs in a polishing bed and using various size steel wheels to apply the abrasive (figs. 17 and 18). Silicon carbide, steel shot, tin oxide, and aluminum oxide abrasives are used to obtain the desired finish. Further finishing operations may employ surface grinding or contour machines (fig. 19), diamond saws (fig. 20), and other specialized machines (figs. 21 and 22). Although large surfacing machines are now almost extinct, junior or baby and medium surfacers are extensively used for finishing granite (fig. 23).

Slabs may be cut by wire saw or gang saws (fig. 24). The wire saw is a twisted or braided endless steel wire ranging in length from approximately 50 to several thousand feet, which cuts by carrying artificial abrasive and water over the surface of the stone. The wire saw leaves a semismooth surface which reduces the work required for further finishing operations. Blocks of granite may also be cut by gang saws, which use steel shot and water.

Slabs are frequently broken into smaller dimensions by splitting along or across the grain with a sledge and bull set (a square-edged, handled chisel) as shown in figure 25. A hammer and hand set may be used to further reduce the stone to size (fig. 26).

Detailed cutting, finishing and fine work on the stones is done with pneumatic hand tools of various sizes and types (fig. 27).

Most inscriptions and designs on monuments and markers are produced by abrasive blasting. Areas to be recessed are cut from a sheet of rubber which is then cemented to the monument (fig. 28). The sandblaster works outside an exhausted enclosure, protected by a thick rubber curtain as shown in figure 29.

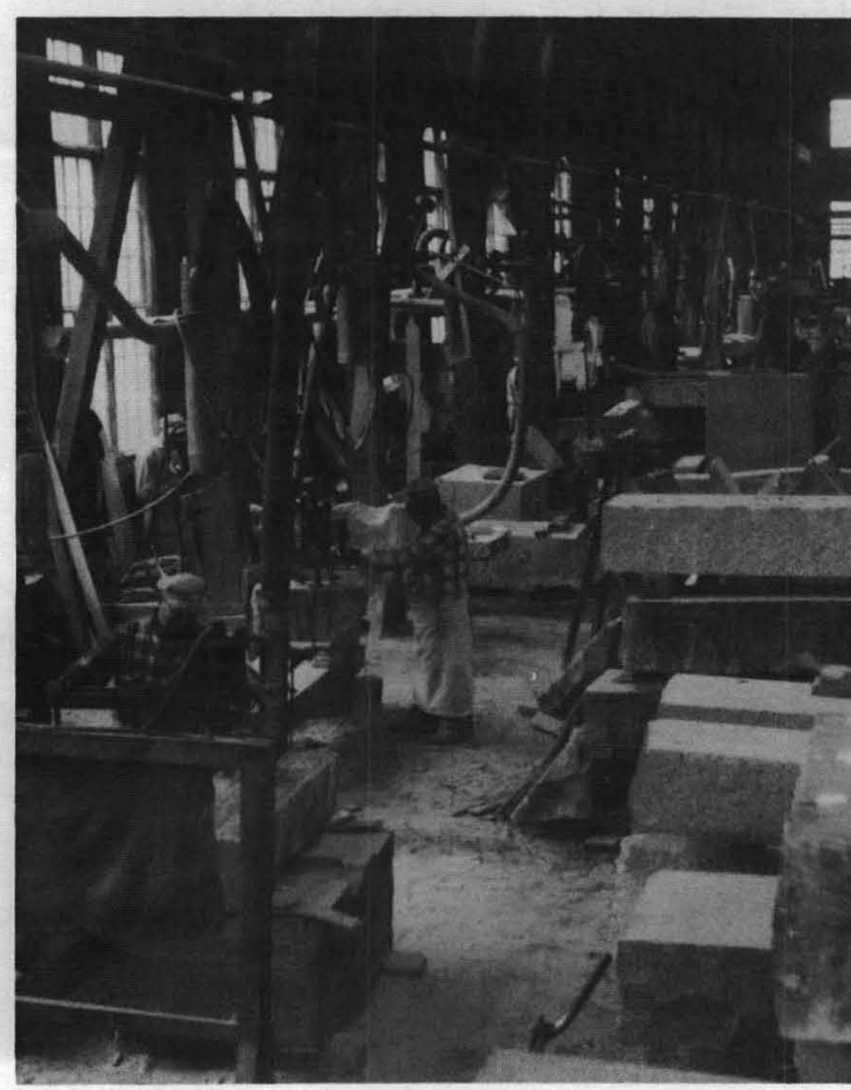


Figure 15. ***General view inside of typical stone shed showing local exhaust at each work station. (1955.)***

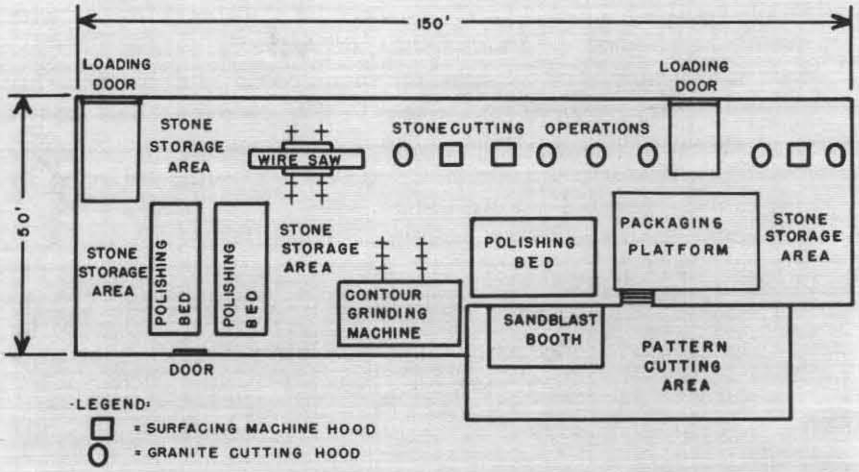


FIGURE 16. *Floor plan of typical granite cutting shed employing about 25 persons. (1955.)*

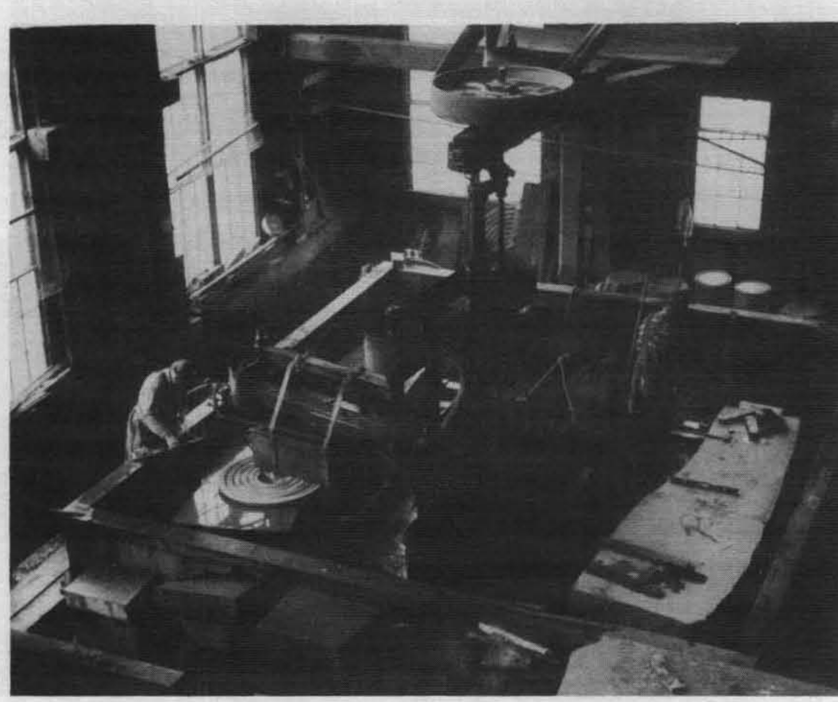


FIGURE 17. *Type of polishing machine in use for over 30 years. (1955.)*

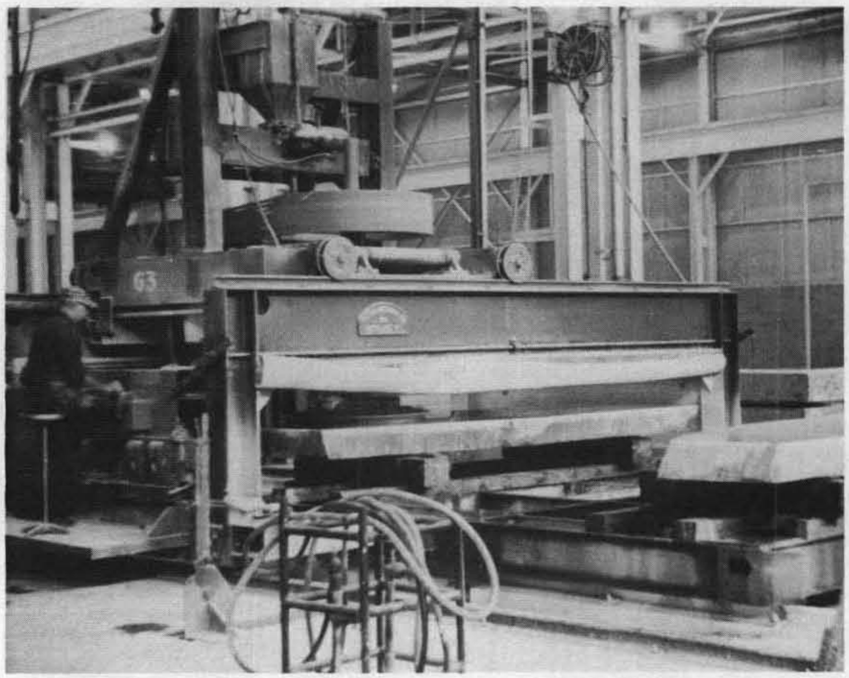


FIGURE 18. *Traveling bed polishing machine in operation in a new shed since 1956.*

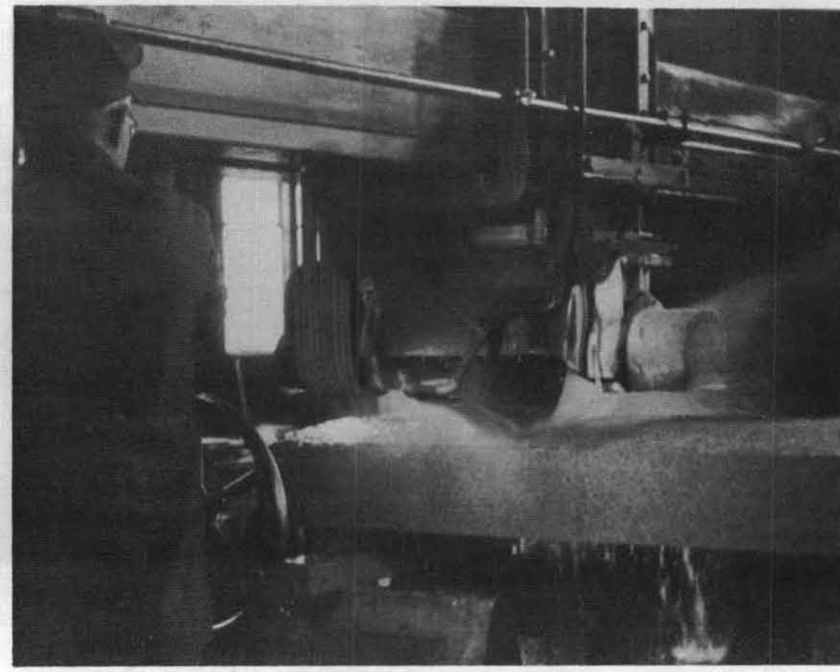


FIGURE 19. *Contour machine making a curved smooth surface on a granite slab. Water used to cool the wheel also keeps down the dust. (1955.)*

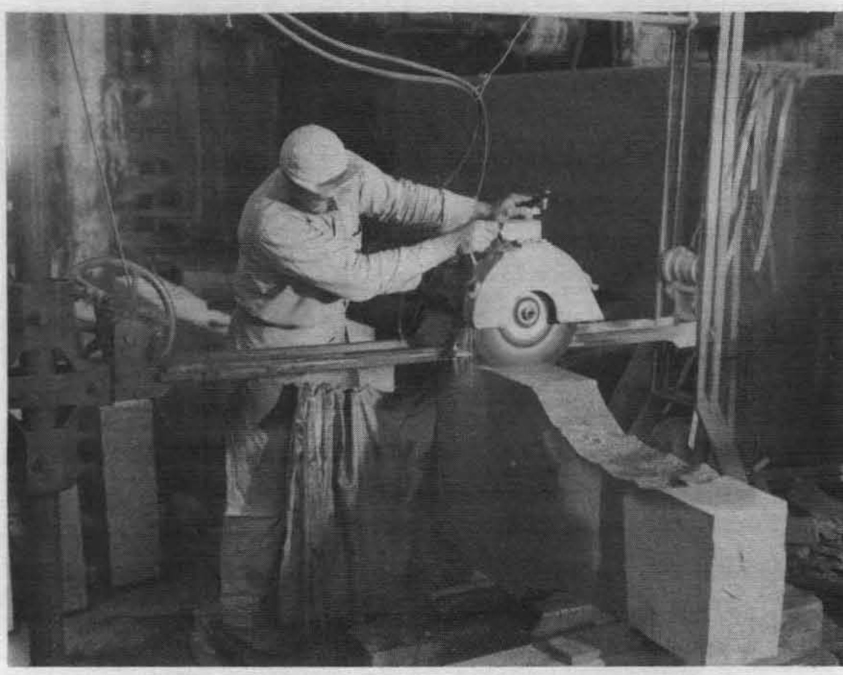


FIGURE 20. *Diamond cutting saw. Note water spray. (Courtesy of Smith, Whitcomb & Cook Co., 1955.)*

The monuments are cleaned by the use of petroleum solvents, muriatic acid, soap and water, and other materials prior to shipment.

The same general operating techniques were used at all of the plants included in the present study.

Sampling Procedures

To insure that a representative group of plants would be studied, plants with over 45 employees, 26 to 44 employees, 11 to 26 employees, and less than 11 employees were grouped separately, and a random selection was made from each of the groups to obtain the total of 20 sheds which were studied.

Each operation performed in a plant was sampled. Not all operations were sampled to the same extent, because certain operations were found in only some of the sheds. For most of the major operations at least 10 breathing zone samples were obtained. In general, the samples were taken throughout a representative cycle of an operation. In some of the hammer and hand-set operations, for example, the worker spent more time in laying out and studying the work than in the actual cutting. Sampling of the operations was not interrupted for such pauses in the work and, as a result, the concentrations obtained are not maximums. "General air" samples were also taken to evaluate the exposure of plant employees.

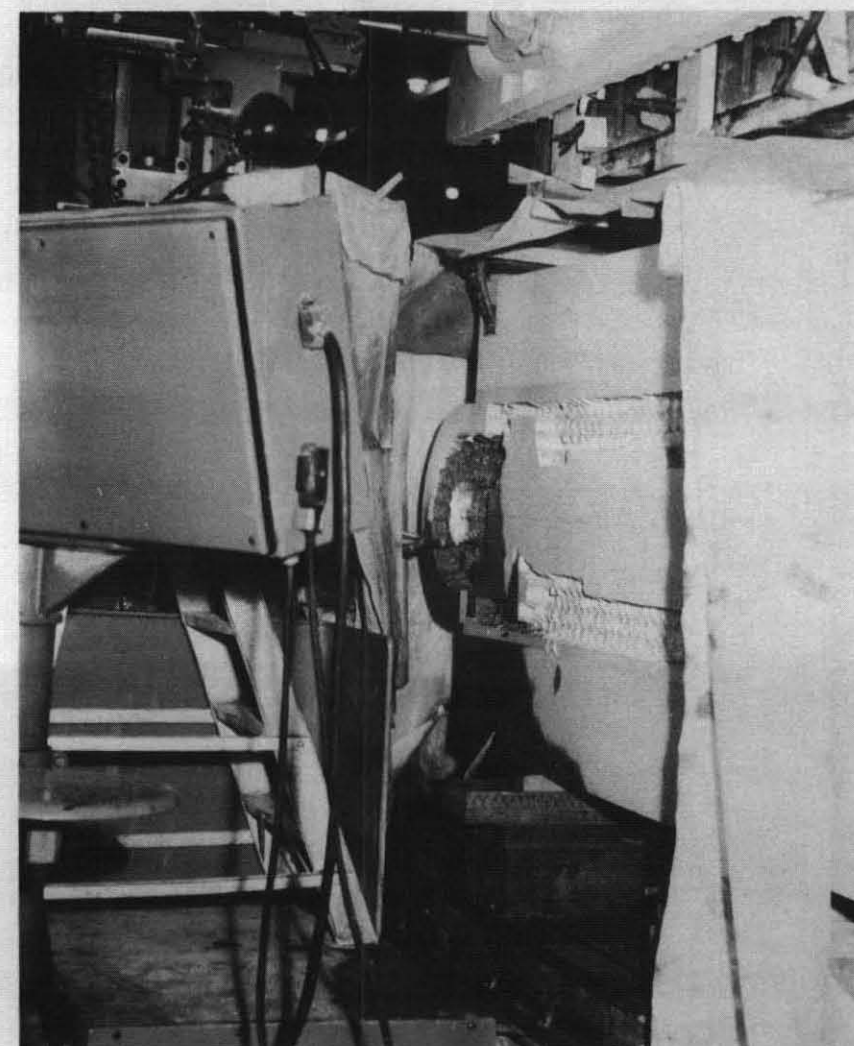


FIGURE 21. *Profiling machine in operation in a new shed since 1956. Stylus following contours in plastic model at top controls the rotating diamond tool in cutting out the design.*

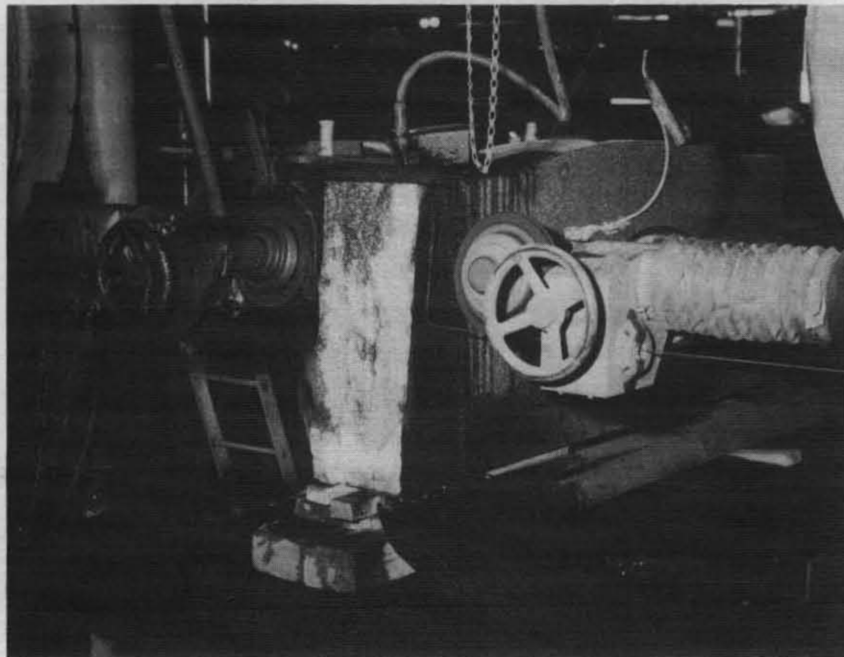


FIGURE 22. *Small wire saw used for cutting curved surfaces. (1957.)*

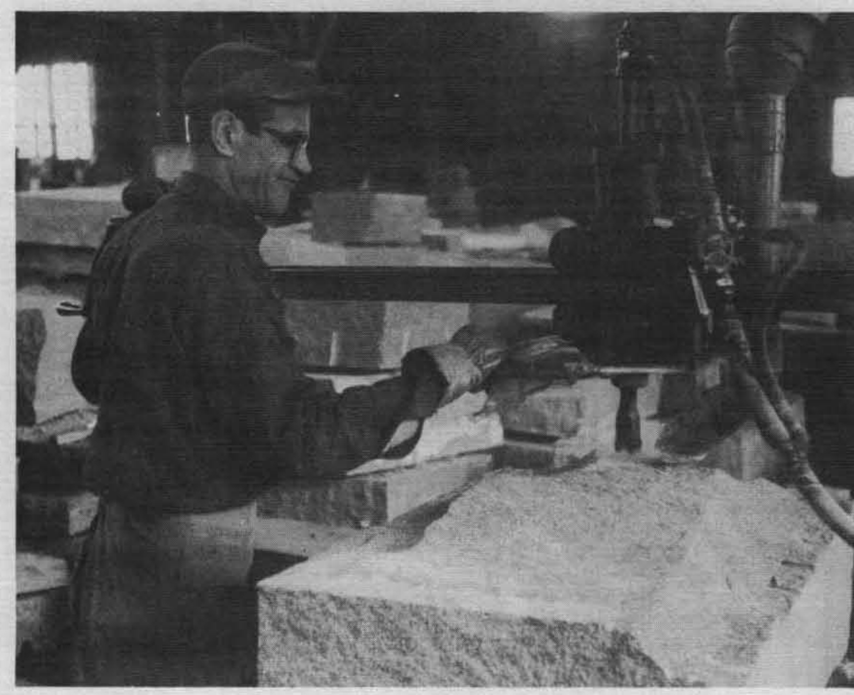


FIGURE 23. *Baby surfacer in operation. Note exhaust hood is permanently attached to the head and remains close to the bit. See figure 6 for contrast with earlier model. (1955.)*

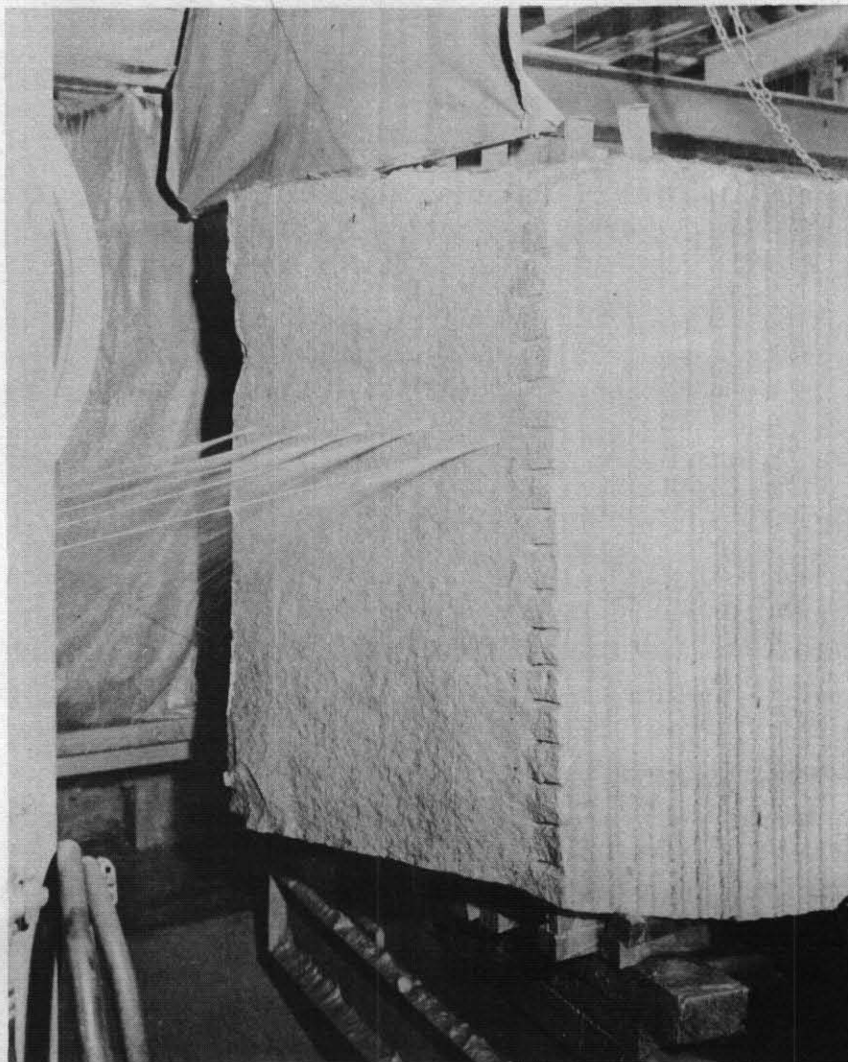


FIGURE 24. *Multiple wire saw. Note abrasive slurry leaving wire. (Courtesy of Smith, Whitcomb & Cook Co., 1955.)*

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FIGURE 25. *Breaking slabs with sledge and bull set.* (1955.)

Methods of Analysis

Samples to determine dust concentrations in the air were taken by impingers. Both the Greenburg-Smith operated at 1 cubic foot per minute and the midget impinger operated at 0.1 cubic foot per minute were used. All impinger samples were counted within 24 hours by the standard lightfield technique using a 10X objective, 10X eyepiece, 1 mm. deep Dunn cells and a 20-minute settling time.

Samples for subsequent size frequency and chemical analysis were collected both with the impinger and the molecular filter. Particle sizes were determined by optical and electron microscope. The optical determinations were made by measuring a large number of individual particle diameters under oil immersion with the Mays (Porton) graticule. The electron microscope determinations were done by the method of Fraser (15). Selected general air samples collected by electrostatic precipitator were sized photometrically by the method of Talvitie and Paulus (16).

Free silica or quartz in the parent rock was determined by the phosphoric acid method of Talvitie (17) and quartz in the airborne dust from electrostatic precipitator samples, by X-ray diffraction. Molecular filter samples were used to determine the total silica by the colorimetric method of Talvitie (18).

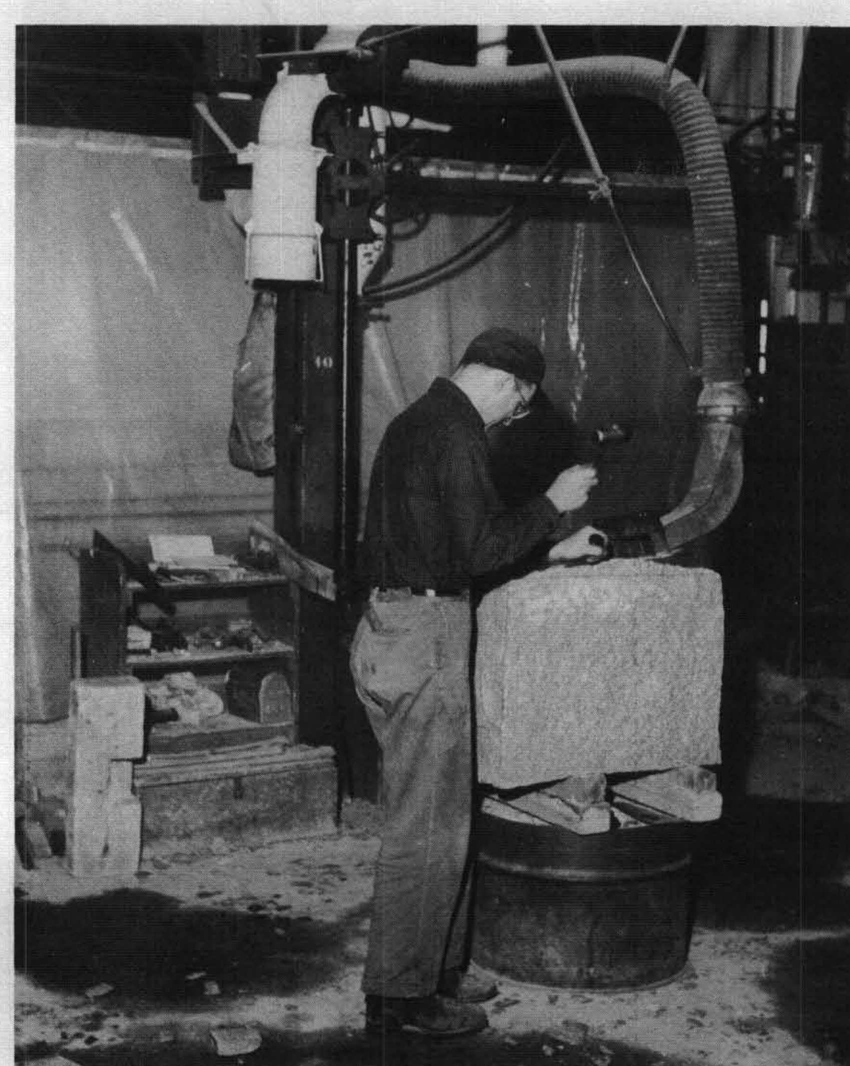

FIGURE 26. *Hand-pitching, one of the oldest hand operations, is still being employed in modern stone-sheds.* (1957.)

FIGURE 27. *Carver sculpturing a bas-relief with a fine pneumatic chisel. Note variety of tool bits used. (1955.)*

FIGURE 28. *Cutting design through sheet of rubber cemented to stone prior to sand-blasting. (1955.)*

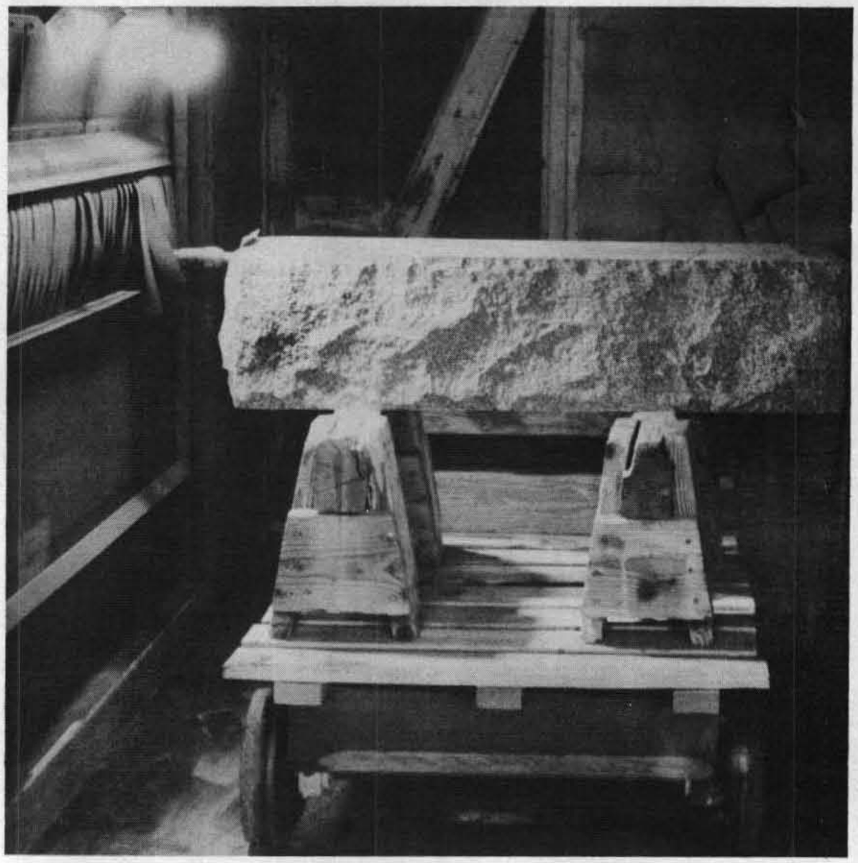

FIGURE 29. *Inside an exhausted sandblast booth. Operator working from behind window is sandblasting an inscription on end of slab. (1955.)*

Results

Dust counts.—Results of the dust counts obtained in the 20 granite sheds are summarized in table 3 by occupation. The average concentrations were quite low; in fact, the only operation which averaged over 10 million particles per cubic foot of air was final polishing. In this operation, handfuls of fine, dry abrasive were tossed on the stone. It was apparent that this abrasive handling was the source of much of the dust observed at the operation. Total silica concentrations at these operations were low, confirming the supposition that abrasive dust was responsible for the high counts obtained.

Not only were the average counts low, but no extremely high maximum concentrations were encountered. In only 24 samples, or

10 percent of the total number was Vermont's threshold limit of 10 million particles per cubic foot of air exceeded, and of this number 10 were at bull setting, hand setting, or hand hammer and chisel operations conducted without the use of the exhaust ventilation.

TABLE 3. *Dust counts in granite sheds by occupation—1955*

Occupation	Number of samples	Dust count (mppcf)[1]			
		Maximum	Minimum	Average	Median
Pneumatic hand tool operators	25	12.0	0.3	3.0	2.2
Carvers	12	11.0	.1	4.5	2.8
Surfacing machine operators	18	14.0	.1	3.3	2.2
Lathe operators	2	8.7	5.7	7.2	----------
Stonecutters using hammer or sledge:					
Exhaust used	7	2.9	.8	1.8	2.2
Exhaust not used	29	21.0	.6	8.8	6.2
Sandblast operators:					
Sandblasting	13	5.4	.2	2.1	2.5
Rubber cutting	7	1.4	.2	.8	.9
Polishers:					
All but final polish	19	9.8	0.4	4.3	3.5
Final polish only	6	59.0	4.7	22.0	13.1
Wire sawyers	11	7.4	.9	2.4	1.5
Cutting wheel operators	11	34.0	.3	5.3	1.5
Contour and grinding wheel operators:					
Wet	8	22.0	.8	6.9	2.3
Dry grinding	2	3.2	.4	1.8	----------
General plant air	53	22.0	.2	3.0	2.2

[1] Million particles per cubic foot of air.

TABLE 4. *Average dust counts in granite sheds by operation—1925, 1937–38 and 1955*

Occupation	Average dust concentration (mppcf)[1]			
	1925 (8)	1937–38 (19)		1955
		Before ventilation	After ventilation	
Pneumatic hand tool operators	59.0	68.3	12.5	3.0
Carvers	37.0	31.9	10.1	4.5
Surfacing machine operators:				
Indoor	44.0	26.8	15.1	3.3
Outdoor	44.0	----------	----------	----------
Lathe operators	18.0	----------	----------	7.2
Stonecutters using hammer or sledge	----------	32.5	8.5	8.8
Blacksmiths	2.5	----------	----------	----------
Tool grinders	27.0	17.3	8.1	----------
Sandblasters	6.2	8.7	8.0	2.1
Gang sawyers	4.6	8.2	7.8	----------
Wire sawyers	----------	----------	----------	2.4
Polishers (including all samples)	9.0	11.0	8.2	8.4
Cutting wheel operators	----------	----------	----------	5.3
Contour and grinding wheel operators	----------	----------	----------	6.9
General plant air	20.0	15.9	5.7	3.0

[1] Million particles per cubic foot of air.

Pointing, the dustiest hand hammer operation, was observed without the use of exhaust ventilation in only one instance.

Dust counts obtained in this study are compared in table 4 with those reported in three previous studies. In all of these studies similar sampling and counting techniques were used so that results may be compared directly.

The dust counts from this study are in general the lowest reported; for most operations they averaged less than one-half of those found immediately after the installation of exhaust ventilation equipment in 1937–38. Exceptions were the hand stone-cutting and polishing operations. Dustiness of hand stone-cutting and breaking was reduced from 32.5 million particles per cubic foot to 8.5 million particles per cubic foot by the introduction of exhaust ventilation in 1937. The average concentration of 8.8 million particles per cubic foot of air for hand stone-cutting obtained in this study indicates that these operations are still being conducted in the same manner as in 1937. Due to the nature of these operations, exhaust ventilation is not always as effective as for other cutting operations. In general, polishing is still conducted in the same manner as in 1925, and the average dust counts at polishers are about the same for the four studies, ranging from 8.2 to 11.0 million particles per cubic foot of air.

The wire saw and various types of grinding wheels were not yet in use at the times of the previous studies; so no comparison is possible. Although the gang saws are still widely used, none was encountered in the sheds studied.

Only a limited number of dust samples were taken in the Barre granite quarries. The results of dust counts in the quarries are compared with previous results obtained in 1933 and 1938 in table 5. The first of these studies indicated average dust counts for leyner drillers in excess of 100 million particles per cubic foot of air, with maxima greater than 1,000 million particles per cubic foot of air. The 1938 study showed quarry drillers still averaging over 100 million particles per cubic foot of air, although the maxima encountered were lower. Since the introduction of year-round wet drilling the average dust count for quarry drillers has been reduced to less than 2 million particles per cubic foot of air as found in the present study.

Similar reductions in dustiness were observed in the plug yard. As in the quarries, the only dry drilling done is in starting the holes, which takes only a few seconds per hole.

The reasons for the further decrease in dust concentrations in the sheds may not be as immediately obvious as in the quarries. Exhaust ventilation systems have been improved since 1938 as the 3- and 3½-inch exhaust hoses and hoods were replaced by 4-inch hoses and hoods and the exhaust ventilating fan speeds have been increased. Recirculation of air from dust collectors has been prohibited since 1948 by

TABLE 5. *Average dust counts in quarries by operation—1933, 1938 and 1955*

Operation	Average dust count (mppcf) [1]		
	1933 (10)	1938 (19)	1955
Leyner drill	144	141	1.1
Plug drill and jackhammer quarry	113	131	1.4
Plug drill—surface yard	37	69	2.7
General air	6	10	

[1] Million particles per cubic foot of air.

regulation of the State Department of Health. Exhaust from the abrasive blasting rooms is also required by the State Department of Health to be passed through approved dust collectors.

Dust size.—The usual method of obtaining a particle size distribution is to measure the diameter of a large number of individual dust particles with an eyepiece micrometer or graticule using a microscope with an oil immersion 97X objective and a 10X eyepiece. When this was done in the present study, very small median particle diameters were obtained by extrapolation.

When the samples were examined under the electron microscope, however, it was found that they contained two types of material. The first was a typical mineral dust; the other a very small, fumelike material. The fumelike material was later found to be a background contaminant, and was present in all outdoor samples taken in Barre during this survey. The electronmicrograph, shown in figure 30, was from a sample collected outside the Barre Court House in December 1955. It shows a preponderance of fumelike material of very small particle size, most of it being less than 0.25 micron.

Figure 31 is an electronmicrograph of a sample from a typical granite-cutting operation with the superimposed smoke, which is clearly distinguishable from the larger granite dust. On the other hand, very little fumelike material is present in the sample shown in figure 32. Since the fine material was obviously nonmineral contaminating dust, it was ignored in the particle sizing by electron microscope. Subsequent samples collected in the summer of 1956 did not show this smoke. In the optical microscope method, it was not possible to separate the two materials. For this reason, results considered to be erroneous were discarded.

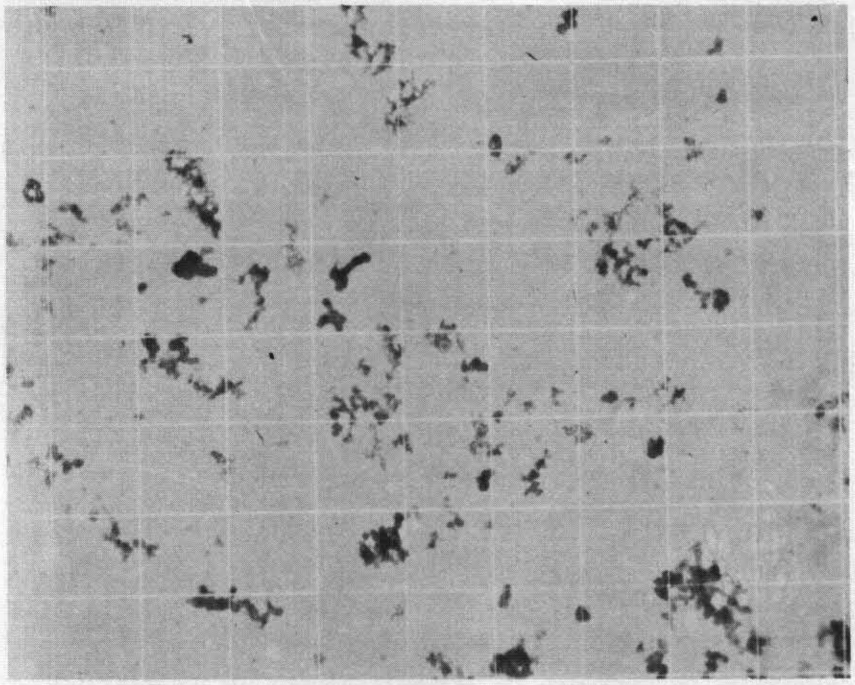

FIGURE 30. *Electronmicrograph of air sample taken outside Barre Court House. Grids are one micron square.*

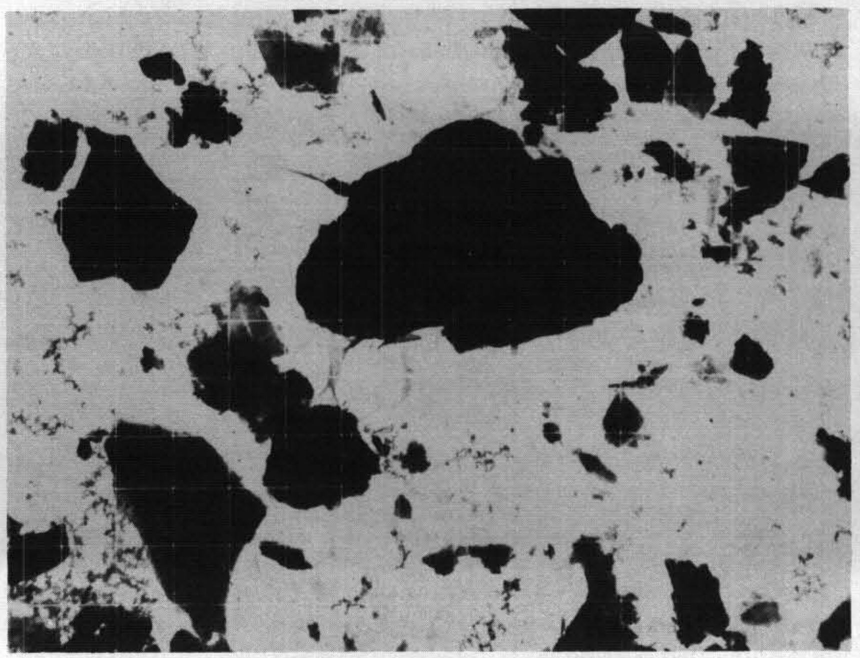

FIGURE 31. *Electronmicrograph of air sample at granite cutting operation. "Fume" superimposed on typical granite dust. Grids are one micron square.*

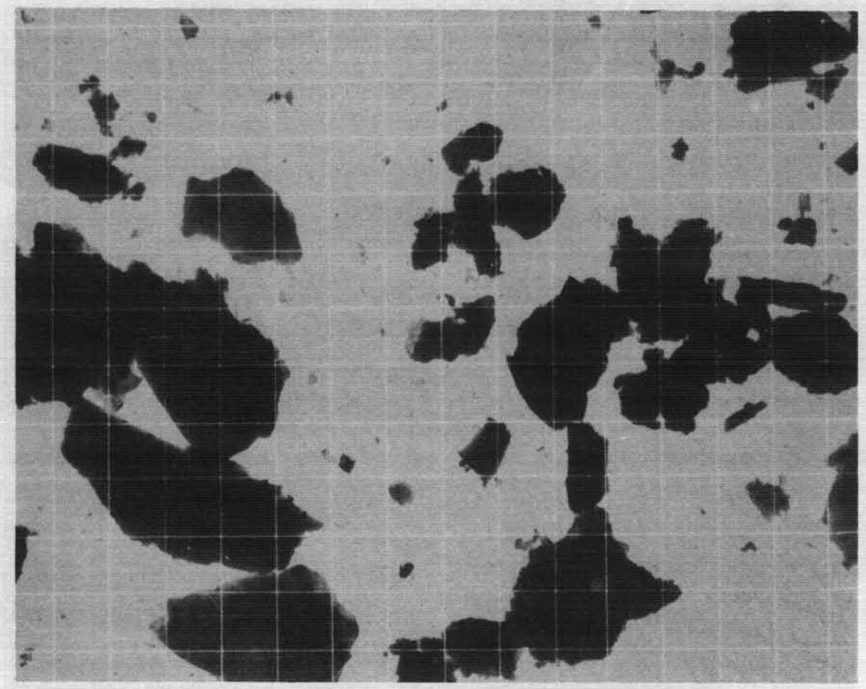

FIGURE 32. *Electronmicrograph of air sample at granite cutting operation. No "fume." Grids are one micron square.*

The median particle diameter of individual samples in the sheds as determined by the electron microscope ranged from 0.7 micron to 1.3 microns, and averaged 1.0 micron. Results are summarized in table 6.

TABLE 6. *Size distribution of dust particles in granite sheds—1955*

Operation	Average median particle diameter (microns)[1]	Standard geometric deviation	Percentage of particles less than 1 micron
Pneumatic hand tool	0.9	2.2	55
Lathe	.9	2.3	55
Contour machine	1.0	2.2	50
Wire saw	1.0	2.2	50
Sandblast	1.0	2.0	50
General air	1.2	2.0	40
Quarry	.5	2.4	77
Plug yard	.3	2.6	90

[1] Ignoring background smoke.

Bloomfield and Dalla Valle (20) in their study of 1938 reported a median particle size of 1.4 microns; whether these results were based on samples collected in Barre is not clear. Urban, however, informed the authors (personal communication) that his studies in Barre showed a median particle size of 1.5 microns. The difference between a median size of 1.0 micron found in the present study and about 1.5 microns in the past studies may be due to the method of sampling.

Membrane filters were used to collect samples for particle size analysis in the present study; their efficiency is about 100 percent for particles larger than 0.1 micron. Particle size determinations were made on 15 samples collected with the molecular filter. An average of 19 percent of the particles were below 0.5 micron, 6.9 percent were below 0.3 micron; and 4.3 percent were smaller than 0.25 micron. Thus about 12 percent of the particles were in the range of 0.3 to 0.5 micron compared with 2 percent in the 0 to 0.49 micron range reported by Bloomfield.

(*Note:* The lower limit of resolution for an optical microscope using light-field illumination is about 0.3 micron. Thus, Bloomfield was in effect reporting the percent of particles in the range of 0.3 to 0.5 micron.)

One of the objectives of the study was to determine the percentage of submicron particles by light-field microscopy. If one assumes that the smallest particle visible to the average observer using an oil immersion objective is 0.3 micron, about 7 percent of the particles could not be sized using this technique. Furthermore, if one assumes that the smallest particle visible to the average observer using a 10X objective and 10X eyepiece is 0.9 micron, nearly 50 percent of the particles would not be counted. This compares with about 31 percent based on Bloomfield's average particle size below 0.9 micron. In actual practice, however, many trained observers are able to see particles about 0.7 micron in diameter. Thus, based on the present data, about 35 percent of the particles would not be counted using the standard light-field technique.

In spite of the differences in median particle sizes previously reported (about 1.5 microns) and that of 1.0 micron found in this study, it is believed that the dust generated in granite cutting sheds today is essentially the same size as in past years. The lower median particle sizes found in samples collected in quarries and plug yards are probably due, for the most part, to background atmospheric dust since the dust counts themselves were only about 2 to 4 times those found in an average city.

Composition of dust.—Samples of the settled dust, parent material and airborne dust were analyzed for free silica. The fraction of the settled dust which was insoluble in hydrofluoric acid, presumed to be principally silicon carbide, was also determined. Results of the analyses are presented in table 7.

It was found that all types of granite used contained essentially the same proportion of quartz. The quartz content of the settled dust was quite different from that found in 1925. Where the operations predominantly involved using wet abrasives to cut and shape the stone (wire saw, machine grinders, cutting wheels), the quartz content of the settled dust averaged 18.5 percent. Dust from areas where the conventional dry cutting tools were used averaged 23.2 percent quartz. These figures compare with the 35.2 percent quartz reported in 1925. Part of this difference is the result of dilution by silicon carbide, as shown by the average silicon carbide content of 11.4 percent in the wet operation areas, and 4.5 percent in the dry operation areas.

TABLE 7. *Free silica (quartz) content of settled and airborne granite dust*

Sample	Number of samples	Percent quartz			Percent silicon carbide [1]		
		Maximum	Minimum	Average	Maximum	Minimum	Average
Parent rock	----------	31.4	27.2	29.1	----------	----------	----------
Settled dust—areas with predominantly wet operations	7	23.2	15.5	18.5	38.1	2.5	11.4
Settled dust—areas with predominantly dry operations	9	26.4	16.0	23.2	14.3	1.0	4.5
Settled dust—type of operation not specified	5	28.3	19.5	24.3	6.6	1.6	3.4
Airborne dust	6	28.0	22.3	24.7	----------	----------	----------

[1] Fraction insoluble in hydrofluoric acid. This is presumed to be mostly silicon carbide, but also includes alumina and other HF insoluble materials.

Since the same method of analysis for quartz was not used in 1925, a further study was made of the present quartz content as compared with that of the past. Samples were taken from beams, which had obviously been undisturbed for many years, high up in two of the older sheds. By taking the sample from the very bottom of the accumulated pile of dust, it was possible to obtain samples perhaps 25 years old. Results of these samples are compared with the other settled dust samples in table 8.

TABLE 8. *Comparison of present settled dust and 25-year-old dust*

Sample description	Percent quartz average	Percent silicon carbide average
All settled dust from 1955 study	21.9	6.8
Settled dust from sheds A and B, 1955	23.2	3.8
25-year-old samples from sheds A and B	29.8	1.3
Rock from 1955 study	29.1	----------
Rock from 25-year-old samples	29.2	----------

Table 8 shows a difference between quartz content of the dust in past years and that at the present time. Part of this difference is due to dilution of the granite dust by silicon carbide, but even excluding the silicon carbide the present quartz content is only four-fifths that of the past. This lower quartz content may be due to dilution by atmospheric smoke and other dust.

The airborne dust samples averaged 24.8 percent quartz, slightly higher than the settled dust samples. Since no airborne samples were taken for free silica analysis in past studies, no direct comparison can be made, but in view of the settled dust results it is probable that the percentage of quartz is now lower.

Total silica.—Total silica (which includes the free and combined silica) was determined on airborne dust collected on molecular filter samples. The results are reported in table 9, and are expressed as milligrams of SiO_2 per cubic meter of air because of the chemical method of analysis. Sixteen samples taken at the dry stone-cutting operations (pneumatic hand tool, surfacer, lathe, and hammer-chisel) averaged 1.36 milligrams per cubic meter (mg/m^3) as compared with 0.63 mg/m^3 for wet abrasive operations and 0.60 mg/m^3 for the general air samples. In other words, air near the dry stone-cutting operations contained approximately twice the amount of granite by weight as air near the wet abrasive operations and the air throughout the shed. Light-field microscopic counts were also made on impinger samples collected simultaneously. It was found that at the dry stone-cutting operations where the dust was mainly granite, the counts averaged 56 million particles per milligram of SiO_2. For dust about these operations which is approximately 90 percent granite containing 70 percent total silica, this would correspond to 35 million particles per milligram of dust. Similar results were obtained by Bloomfield (12), who stated that industrial dust counted by the same technique contained 30 million particles per milligram.

TABLE 9. *Total silica (SiO_2) content of airborne dust in granite shed*

Operation	Number of samples	Total silica (SiO_2) in mg/m^3 [1]		
		Maximum	Minimum	Average
General air	8	1.0	0.21	0.60
Pneumatic hand tool cutting	5	3.2	.85	1.63
Carving	5	1.78	.38	1.16
Surfacing	1			.46
Lathe	1			.21
Hand stonecutting	4	3.24	1.15	1.78
Sandblasting	1			.60
Wire sawing	5	.95	.09	.40
Polishing	5	3.80	.25	1.16
Cutting wheels	1			.67
Contour and grinding wheels	6	.60	.18	.33
Rotary saw	1			.88
Dry grinding	1			.48

[1] Milligrams SiO_2 per cubic meter of air.

Spectrographic analysis.—To determine the constituents of the airborne dust further, electrostatic precipitator samples were analyzed by emission spectrograph. Silicon and calcium were classed as major (more than 2 percent) constituents, since the amounts present were beyond the range of spectrographic analysis. Iron, sodium, and tin were moderate constituents (over 1 percent). Potassium was present in a small amount (less than 1 percent), and traces of arsenic and thallium were found. Results of a semiquantitative procedure for other elements are shown in table 10. Toxic elements found included lead at approximately 1 percent of the threshold limit, mercury at 0.03 percent of the threshold limit, and beryllium at 0.1 percent of the suggested threshold limit. Other elements were present in lower concentrations relative to their threshold limits. Chromium, titanium and barium were found in much higher concentrations in one sample than in the others; so the high sample is presented separately from the average of the others.

TABLE 10. *Results of spectrographic analyses of airborne dust in granite sheds*

Element	Average (micrograms per milligram of sample)	Average (micrograms per cubic meter of air)
Silicon	Major constituent	(>2%)
Calcium	Major constituent	
Iron	Moderate constituent	(>1%)
Sodium	Moderate constituent	
Tin	Moderate constituent	
Potassium	Small amount	(<1%)
Aluminum	25.0	38.0
Magnesium	2.3	3.4
Zinc	1.4	2.1
Lead	.9	1.3
Manganese	.8	1.2
Nickel	.04	.06
Vanadium	.04	.06
Mercury	.02	.03
Cobalt	.02	.03
Cadmium	.01	.02
Antimony	.01	.02
Beryllium	.002	.003
Chromium (5 samples)	.05	.08
Chromium (1 sample)	6.4	9.6
Titanium (4 samples)	.2	.3
Titanium (1 sample)	>>2.0	>>3.0
Barium (4 samples)	.09	.13
Barium (1 sample)	>1.6	>2.4
Arsenic	Trace	
Thallium	Trace	

Total dust load.—In the process of analysis of electrostatic precipitator samples, the dust was weighed. Concentrations of dust in these samples, which were not taken in the immediate vicinity of any one operation, ranged from 0.97 to 2.22 mg/m^3 and averaged 1.5 mg/m^3.

Discussion

The environmental resurvey of the Vermont granite industry showed that dust concentrations were lower than those reported in previously published data and confirm the low dust counts being found by the Vermont Industrial Hygiene Division. Average counts were well within the Vermont threshold limit of 10 million particles per cubic foot for this type of dust. The decrease in dustiness is an outstanding example of effectiveness of the combined efforts of management, labor, and an official agency in reducing a serious health hazard. The ever changing production methods, however, make it necessary for plant officials to be constantly on guard against setting up new processes that might increase dust production.

Status of Silicosis, 1950–55

Dust counts taken over the past 18 years in the Vermont granite industry have shown that concentrations of silica dust have been gradually reduced to within threshold limits that presumably will not produce silicosis. A lapse of 18 years is hardly long enough to determine the ultimate effect of modern dust control methods on the suppression of silicosis because of its inherently slow development and chronic nature. However, in view of the previously high prevalence of the disease and the short periods of exposure associated with many cases, it is believed that taking stock of the progress reflected thus far is warranted.

To determine the nature of this progress, records of chest X-ray examinations of granite shed workers that the Vermont Industrial Hygiene Division has been accumulating since 1937 were used. Mortality records were also used to a limited extent.

In the following sections the annual prevalence of silicosis among employed granite shed workers is discussed. Based on cumulative records covering the 6-year period 1950 through 1955, observations are made on characteristics of the study group bearing on the nature of the silicosis problem such as age, years of employment, years to develop silicosis, and occupation.

Only broad generalizations are made since the chest X-ray records were not kept with the idea of making statistical studies. Despite limitations, however, the records represent the best information of this kind available in the State as well as in the country. Moreover, because of the long period over which they have been maintained, they permit making certain deductions which could not be made otherwise on progress in preventing silicosis in the granite industry.

Attention is also called to the fact that the analyses are limited to granite shed workers. Over the years 1950 to 1955, there were 52 cases of silicosis among granite quarry workers on record, including 13 known dead. These figures are excluded since comparable data on the quarry population at risk were not obtained. Insofar as the records show, all had some work experience under uncontrolled dust conditions. When the silicosis problem in the granite industry is evaluated, these cases should be remembered.

Annual Prevalence of Silicosis Among Employed Workers

In 1956, 244 men with X-ray evidence of silicosis were still working in the sheds, or a rate of 15.1 percent. In 1937–38, some 18 years previously, 45.3 percent of the men X-rayed were found with silicosis in one stage or another. The rates for 1952 through 1956, and for 1937–38 as calculated by the Industrial Hygiene Division are shown in table 11. According to these figures the proportion of employed workers with silicosis has been dropping steadily.

TABLE 11. *Annual prevalence of silicosis among employed granite shed workers, based on chest X-ray examinations, 1937–38, and 1952 through 1956*

Item	1937–38 [1]	1952	1953	1954	1955	1956
Number on payroll	2,400	1,736	1,810	1,809	1,660	1,694
Number X-rayed:						
In specified year	805	1,387	1,453	1,437	1,353	1,390
In specified or previous years	----------	1,572	1,685	1,698	1,576	1,617
Percent of payroll X-rayed:						
In specified year	33.5	85.8	81.4	84.9	86.6	86.9
In specified or previous years	----------	90.6	93.2	93.9	95.0	95.5
Number with silicosis and suspected infection	143	58	62	42	39	40
Number with silicosis, all forms	365	319	322	294	250	244
Percent of X-rayed workers with silicosis, all forms	45.3	20.3	19.1	17.3	15.9	15.1

[1] These figures are based on a reanalysis of X-ray records and differ somewhat from those reported by Judd (11). Number on payroll is State total.

Because of the voluntary nature of the chest X-ray program, some workers do not appear for X-rays annually. The Industrial Hygiene Division has been successful, however, in reaching between 81 and 87 percent of the employees since 1952. When men X-rayed prior to the specified years and still on the payroll are added, the proportions average between 90 to 96 percent. A recheck of the records of the 223 men counted in the 1955 total but X-rayed in previous years showed that all but 12 had been X-rayed since 1950. These 12 were older men with many years of exposure to dust, and it is conceivable that a few of them might now be affected. The prevalence rates, however, would not be materially changed because of the small numbers involved. The rates shown for 1952 through 1956, therefore, can be considered fairly indicative of the current prevalence of silicosis in the sheds.

It is obvious from table 11 that on the basis of number of cases, the decrease in prevalence does not appear striking. In 1937–38, the records show 365 cases of silicosis; in 1952 the number was 319 and in 1953, 322. Numerical comparison with 1937–38 is not entirely justifiable since only one-third of the 2,400 men then employed in the entire State were X-rayed as contrasted with the larger proportions reached in the recent years.

A better idea of the decrease in the number of employed men with silicosis can be obtained by using the projected figures of Judd (11). On the basis of the men X-rayed in 1937-38, he estimated that among the 2,100 shed workers employed in the Barre area there were probably some 555 simple or complicated silicosis cases, and another 300 to 350 borderline cases. The projected figures take into account the occupational distribution of men employed in the sheds at that time and their dust exposure, and probably are fairly reliable. Comparison of the 555 cases in 1937–38 with the 244 cases in 1956 gives a better idea of the drop that probably actually occurred in the past 18 years.

The gradual decrease in prevalence of silicosis can be unquestionably attributed to dust control. In part it is also due to deaths and to withdrawals of affected men from the industry because of disability, retirement, or changes in occupation. New cases among previously exposed workers are still appearing, but the number is continuously diminishing.

Extent of Silicosis in Study Group, 1950–55

To obtain some insight into the nature of the prevailing silicosis problem associated with granite shed workers, records were analyzed of 2,246 individuals X-rayed one or more times, or known to have died during the 6-year period 1950 to 1955. As contrasted with the preceding section, this figure includes in addition to men currently employed, those no longer working, or working at other trades but who appeared for chest X-rays during the study period. Included also are all known deceased granite shed workers with a diagnosis of silicosis whether they had been X-rayed or not, and who could be traced through death certificates or newspaper notices. In brief, an attempt was made to include as much usable data as possible that would shed light on the social as well as industrial impact of the disease.

Among the 2,246 men in the study group, 535 or 25 percent had silicosis in one stage or another. This percent, however, is only a measure of the proportion of the study group affected, and not of the total prevalence.

The cumulative status of the 2,246 men at some point during the 6-year period is as follows:

2,001 men—working in granite sheds at time of last X-ray; 367 showed evidence of silicosis.

75 men—former granite shed workers; either no longer employed or employed at nondusty jobs, who continued to appear for X-rays; 32 had evidence of silicosis.

170 men—deceased; X-rayed at some time since 1937 or identified through death certificates; 136 had evidence of, or died from silicosis or silico-tuberculosis.

The death certificate search, made by the National Office of Vital Statistics, covered 1950, and 1952 to 1955. Certificates for 1951 were no longer available. All death certificates stating silico-tuberculosis or silicosis as either a primary or contributory cause of death were transcribed. This source produced 91 cases among granite workers, on 47 of whom there were also X-ray records. Notice of the other 45 deceased men was obtained through newspaper obituaries which the Industrial Hygiene Division checks routinely. Each had been X-rayed at some time since 1937 and found to have silicosis or suspected silico-tuberculosis. Their deaths, however, were apparently attributed to causes other than silicosis or silico-tuberculosis. Further check of death certificates for causes of death was not made.

Over three-fourths of the 2,246 workers had chest X-rays or had died in 1954 or 1955. Thus, although a 6-year period is covered, the majority of the persons relate to a current period.

The rate at which new cases of silicosis were uncovered in the study group was governed primarily by the success in reaching workers through the X-ray program. Thus, of the 535 men with silicosis, 491 have been X-rayed one or more times. Death certificates only were available on the remaining 44 cases. There was evidence of silicotic changes on the first and subsequent X-rays for all but 158 men. A distribution of the cases according to period when they received their first X-ray and when the diagnosis of definite silicosis was made follows:

Period	First X-ray	Diagnosis of silicosis	
		Number	Percent
1937–39	152	56	11.4
1940–44	94	75	15.3
1945–49	79	97	19.7
1950–55	166	263	53.6
Total	491	491	100.0

For example, 56 of the 152 men X-rayed during 1937–39 were found with silicosis during this period; in the other 96, silicosis was not evident on the X-rays until subsequent years, some not until 1950–55.

The comparatively large number of cases found during 1950–55 is due in part to the acceleration of the X-ray program. In 1950, 66 new cases were picked up, 93 cases in 1951, 60 cases in 1952, and 32 cases in 1953. Although the numbers X-rayed in 1954 and 1955

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continued to be high (see table 2) only 5 new cases were picked up in 1954, and 7 in 1955. These figures suggest that the uncovering of new cases may be tapering off.

To determine the effect of dust control on the production of silicosis, 1937 was taken arbitrarily as separating precontrol and dust-control periods, and the 2,246 men classified according to these two periods. A total of 1,112 men gave histories of having started working in the granite or other dusty industry before 1937, and 1,134 in 1937 or after. Tables 12 and 13 and figures 33 and 34 present comparative distributions of these two groups by age and years of employment in dusty occupations, and by diagnosis of silicosis. A discussion of the characteristics of these groups follows.

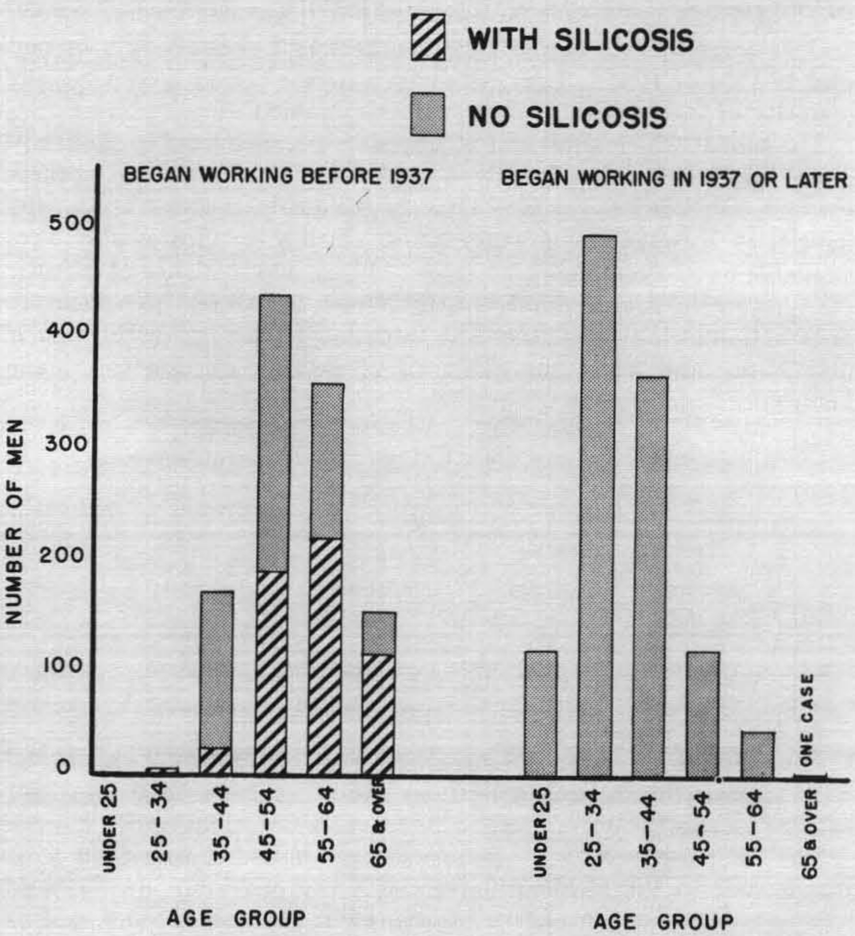

FIGURE 33. *Age distribution of Vermont granite shed workers in study group, 1950–55*

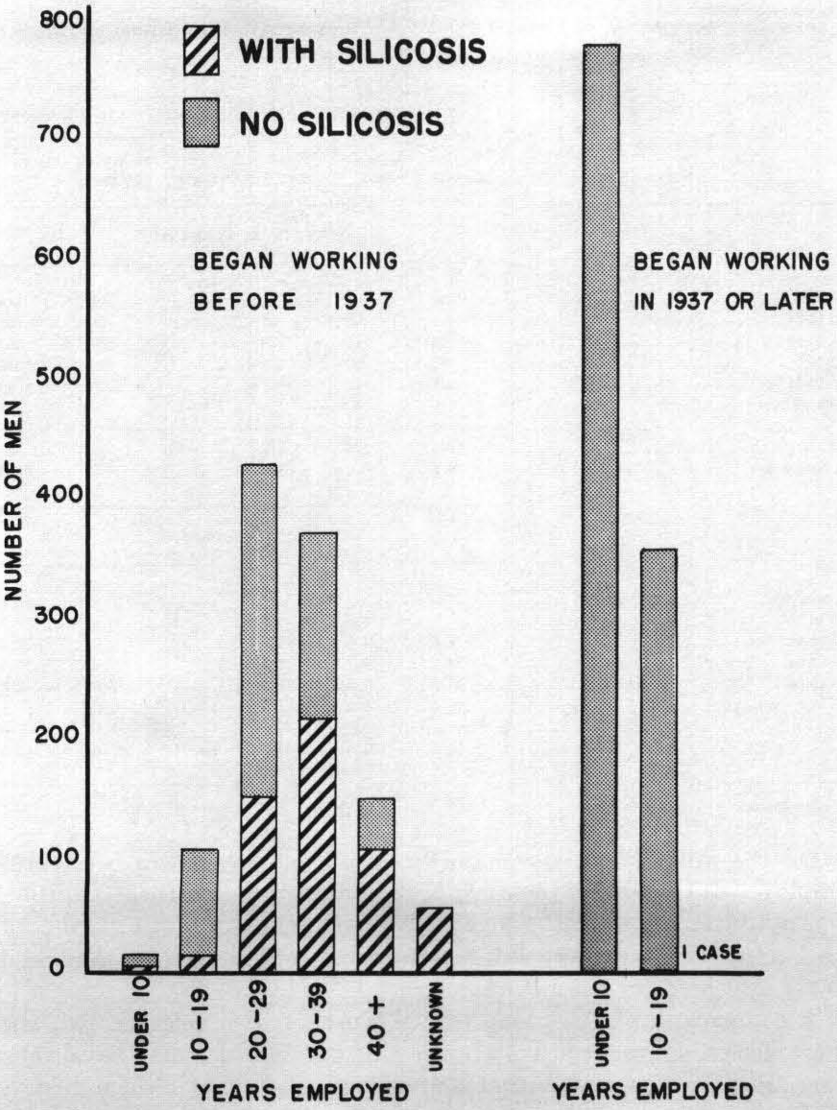

FIGURE 34. *Years employed in granite industry by workers in study group, 1950–55*

Silicosis Among Men Starting Work in the Granite Industry Before 1937

Of 1,112 persons who started work in the granite sheds before 1937, silicosis in one stage or another was diagnosed in 534 or 48 percent. Between 1950 and 1955, 136 of this group died. Since mortality information is not complete, the number of fatal cases of silicosis may be actually higher.

TABLE 12. *Distribution of Vermont granite shed workers with silicosis and no silicosis by dust exposure period and age, 1950–55*

Age group	Began working before 1937			Began working in 1937 or later		
	With silicosis	No silicosis	Total	With silicosis	No silicosis	Total
	NUMBER OF WORKERS					
Under 25					114	114
25 to 34		3	3		491	491
35 to 44	24	144	168		363	363
45 to 54	185	249	434		118	118
55 to 64	215	142	357		41	41
65 and over	110	40	150	[1] 1	6	7
Total	534	578	1,112	1	1,133	1,134
Average age	59.3	50.6	53.9		35.0	35.0
	PERCENT OF WORKERS					
Under 25					10.1	10.1
25 to 34		0.5	0.3		43.4	43.3
35 to 44	4.5	24.9	15.1		32.0	32.0
45 to 54	34.6	43.1	39.0		10.4	10.4
55 to 64	40.3	24.6	32.1		3.6	3.6
65 and over	20.6	6.9	13.5	100.0	.5	.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1] Suspected.

On the other hand, the majority of the affected group were still employed at the time of their last X-ray, indicating that their condition was not totally disabling. No estimates are available of the number of granite workers who may still be living and totally disabled, and who never appeared for chest X-rays.

A comparison of the group of 534 workers with silicosis with the "no silicosis" group brings out interesting points which may have some bearing on the possible continued prevalence of silicosis in the industry. First, the affected group has worked longer than the unaffected group. The average number of years of employment for the men with silicosis is 32.4 and for the others 26.3. Almost 60 percent of the affected men have already worked 30 years or longer; 107 of these had as much as 40 years or more employment. These numbers exclude 44 fatal and 3 nonfatal cases in the upper age groups for whom employment histories are not known. Assuming that men of the same age have equivalent exposures and including them, it is safe to estimate that at least two-thirds of the affected men have already worked 30 or more years, usually considered a normal working life span. This is indeed a striking contrast to the early days of uncontrolled dust when the average granite shed cutter expected after 20 years or more of earning good wages and living well to become an invalid for a year or two and to die from silico-tuberculosis at least 10 years sooner than men who were not employed in granite sheds (11).

Secondly, the affected workers are likewise older than the nonaffected group. The average age of men with silicosis is 59.3, and for the others, 50.6. Twenty-four men with silicosis were under 45 years of age (none was under 40) as compared with 147 in the "no silicosis" group. (Of 150 persons reaching the ages of 65 and over, 110 had silicosis.) It would seem from these findings that as the nonaffected group advances with age and length of employment, some will eventually have silicosis because of their previous dust exposure. As a matter of fact, 45 men classified in the "no silicosis" group already have X-ray evidence of pulmonary fibrosis.

TABLE 13. ***Distribution of Vermont granite shed workers with silicosis and no silicosis by dust exposure period and years of employment, 1950–55***

Years of employment	Began working before 1937			Began working in 1937 or later		
	With silicosis	No silicosis	Total	With silicosis	No silicosis	Total
	NUMBER OF WORKERS					
Under 10	2	13	15		778	778
10 to 19	15	89	104	[1] 1	355	356
20 to 29	148	277	425			
30 to 39	211	158	369			
40 and over	107	41	148			
Not known	51		51			
Total	534	578	1,112	1	1,133	1,134
Average years	[2] 32.4	26.3	29.1		7.4	7.4
	PERCENT OF WORKERS					
Under 10	0.4	2.3	1.3		68.7	68.6
10 to 19	2.8	15.4	9.4	100.0	31.3	31.4
20 to 29	27.7	47.9	38.2			
30 to 39	39.5	27.3	33.2			
40 and over	20.0	7.1	13.3			
Not known	9.6		4.6			
Total	100.0	100.0	100.0	100.0	100.0	100.0

[1] Suspected.

[2] In the calculation of this average, the 51 cases for whom employment histories were not known were excluded.

The increasing longevity and working span of men with silicosis is probably the result of numerous factors. A great deal of the improving situation can be attributed to control of dust over the past 18 years and the consequential lessened liability to tuberculosis. It had been observed as early as the twenties that uncomplicated silicosis can run a long course, offering little inconvenience to the men in their work. Because of the high exposures to dust in those days, very few cutters escaped infection then. That today's silicotics are able to remain at their occupations as long as they do is indeed a sign of remarkable progress. On the other hand, because of their condition, they undoubtedly contribute to the public health problems of an aging population.

Silicosis Among Men Starting Work in Granite Industry in 1937 or After

As was mentioned earlier, only one worker X-rayed with a history of starting work in a granite shed since 1937 was diagnosed as having suspected silicosis. The man was 74 years old in 1954 and had been a maintenance worker in a shed since 1941 or for some 13 years. Because of his age and work experience, there is some question as to the validity of the diagnosis. He claims that previously he worked as a carpenter and had no other exposure to silica dust. Upon followup, the Vermont Industrial Hygiene Division found that the man's exposure to silica dust in the shed was incidental. Serial X-rays taken in 1952 through 1954 demonstrate suspected early nodular silicosis. The man was retired in 1955, and his whereabouts could not be traced.

The other 1,133 workers in the group are relatively young, suggesting that in the past 18 years the granite industry has been employing large numbers of new employees, especially apprentices. Over 85 percent are under 45 years of age, with only 4.1 percent over 55 years. The average age for the group is 35 years and average length of employment, 7.4 years. Of the 356 workers with over 10 years of employment, 100 had as many as 15 to 18 years.

Occupational Experience of Study Group, 1950–55

A distribution of occupations of men with silicosis and the two nonaffected groups is given in table 14. The occupations are based on the brief occupational histories obtained at the time of the X-ray and are classified according to dust-exposure groups developed in the 1924–26 study. They reflect the lifetime work experience and are not necessarily the current or last occupations carried on. Occupations of workers at the time of their 1954 or 1955 X-rays are discussed on page 8. The habit of workers shifting from one occupation to another and of performing several types of duties in smaller sheds makes a rigid grouping according to single occupation or potential dust-exposure group impossible.

TABLE 14. *Occupational experience of the 2,246 individuals in study group 1950–55, classified according to dust-exposure groups used in 1924–26 study*

Occupation	With silicosis [1]	No silicosis		Total
		Began working before 1937	Began working after 1937	
More than average plant dustiness				
Group A:				
Hand pneumatic-tool operators, carvers, letterers	198	77	260	535
+manufacturer, foreman	38	13	3	54
+surface machine operator	33	15	10	58
+tool grinder	6	3	3	12
+jobs in Group C	27	41	26	94
+other jobs in Group D	48	22	42	112
+employment in quarry or other dusty work	9	6	20	35
Subtotal Group A	359	177	364	900
Group B:				
Surface machine operators	14	8	12	34
+jobs in Group C	2	3		5
+jobs in Group D	2	4	3	9
+employment in quarry	1	1	1	3
Tool grinders	8	8	21	37
+jobs in Group C	3	8	13	24
+jobs in Group D		6	7	13
+employment in quarry or other dusty jobs		2	2	4
Subtotal Group B	30	40	59	129
Average plant dustiness				
Group C:				
Polisher, bedsetter	36	51	121	208
+other jobs in Group C	5	5	23	33
+jobs in Group D	6	14	16	36
+employment in quarry or other dusty jobs	3	9	6	18
Lumper	19	27	107	153
+other jobs in Group C	1	6	9	16
+jobs in Group D		8	15	23
+employment in quarry or other dusty jobs	2	13	11	26
Boxers, mechanics, laborers, miscellaneous	21	59	145	225
+jobs in Group D		9	12	21
+employment in quarry or other dusty jobs	6	22	23	51
Subtotal Group C	99	223	488	810
Less than average plant dustiness				
Group D:				
Sawyers	3	19	85	107
+jobs in Group D		2	2	4
+employment in quarry	1	5	10	16
Sandblast operators	13	23	61	97
+jobs in Group D	2	8	8	18
+employment in quarry or other dusty jobs	1	5	3	9
Derrickmen, cranemen	6	31	33	70
+employment in quarry		2	4	6
Blacksmiths	5	10		15

TABLE 14. *Occupational experience of the 2,246 individuals in study group 1950–55, classified according to dust-exposure groups used in 1924–26 study*—Continued

Occupation	With silicosis [1]	No silicosis		Total
		Began working before 1937	Began working after 1937	
Group D—Continued				
+employment in quarry		1	1	2
Owners, foremen	8	29	15	52
+employment in quarry		2		2
Not stated and all other	8	1		9
Subtotal Group D	47	138	222	407
Total—all groups	535	578	1, 133	2, 246

[1] Includes the one case of suspected silicosis in a worker who entered the granite industry after 1937.

The highest prevalence of silicosis continues to be among men with total or partial work experience as pneumatic-tool cutters, carvers, and letterers, surface machine operators, and tool grinders, or in occupations usually associated with high dust concentrations. Almost three-fourths (73 percent) of the 535 silicotics worked at these occupations at some time or another (groups A and B in the table). The other one-fourth of the cases was distributed among occupations associated with potentially low exposures (groups C and D).

Granite shed workers have always shown a tendency to remain in the same industry, though they may shift from one occupation to another. This apparently still holds true, for only 8 percent of the 2,246 workers gave histories of having some employment in granite quarries or in foundries, talc, slate, asbestos, or mining industries.

When compared with previous investigations, the outstanding fact observed is that more cases are showing up at present among the low dust-exposure groups than in the 1924–26 and 1937–38 studies. For instance, Judd in 1937–38, found about 10 cases of silicosis among 200 workers classified in the low exposure groups. In the 1924–26 study, the number of cases attributed to low exposures is hard to determine, but apparently was quite small. Similar results were obtained on the reexamination of 166 men in 1937–38. Whereas all but one of the workers in the high exposure group had progressed to silicosis, only 2 out of 33 in the low exposure group had developed definite silicosis in the meantime. It was possible to trace further 18 of these workers through the X-ray records. By 1950–55, 4 of the originally examined men were still negative; 5 showed definite silicosis; 3 developed suspected tuberculosis but no silicosis; and 6 developed silico-tuberculosis. Of the last group, 4 had died before 1950. The one worker in the high exposure group who had no lung changes in 1924–26 and 1937–38, also developed silicosis. These findings, together with subsequent data on years required to develop silicosis, suggest that silicosis will eventually occur among some workers with low dust exposure who remain at their jobs for their working life.

Silicosis Complicated With Tuberculosis

Tuberculosis is the commonest and most important complication in silicosis and is responsible for the majority of deaths among men with silicosis. The findings on extent of silicosis complicated with tuberculosis insofar as this analysis is concerned, are to be regarded as tentative as the records on diagnoses of infection, presumably suspected tuberculosis, are limited to roentgen interpretation only. Suspected tuberculosis in either active, inactive, or activity undetermined stages was diagnosed in 88 or 22 percent of the 399 silicotics still living at the time of the last X-ray and was a cause of death in 75 or 55 percent of the 136 deceased cases. The average ages and years of employment for the two groups is shown in the accompanying table.

Item	Alive			Dead		
	Silicosis	Suspected silico-tuberculosis	Total	Silicosis	Silico-tuberculosis	Total
Number of cases	311	88	399	61	75	136
Percent of cases	78	22	100	45	55	100
Average age	55.7	56.2	55.8	62.9	61.5	61.6
Average years of employment [1]	32.0	32.6	32.1	34.2	28.0	33.3

[1] The 47 cases for whom employment histories are not available are excluded from calculation of these averages.

The tabulation shows practically no difference in average ages and years of employment for men alive at the time of the last X-ray with simple silicosis or with suspected tuberculosis also. The deceased group is about 6 years older on the average than the living, but within the group, average ages are about the same. The only difference is in average years of employment which is 34.2 for those with silicosis and 28 for those who also had suspected tuberculosis. The latter averages may be affected by the smaller numbers used in calculations as employment histories were not known for 44 of the deceased group.

Length of Exposure Required to Produce Silicosis

The average number of years of exposure to dust required to produce silicosis in the present study group is based on serial X-ray observations of 153 men who showed changes from normal chests or pulmonary fibrosis to definite silicosis between 1937 and 1955. Thirty-two of these persons entered the granite industry before 1920, 113 between 1920 and 1929, and 8 after 1930, but before 1937. The average number of years for the entire group is 26, with durations varying from 12 to 50 years. When the group is classified according to diagnosis and occupation, the following differences were found:

Diagnosis	Pneumatic tool cutters	Polishers, lumpers, sand-blasters, etc.
Silicosis:		
Number of workers	79	39.
Average	23 years	29 years.
Range	12 to 44 years	17 to 50 years.
Silicosis and suspected tuberculosis:		
Number of workers	24	11.
Average	28 years	27 years.
Range	19 to 39 years	19 to 40 years.

Comparisons with earlier studies are not satisfactory; usually only the average number of years of employment is known, which is not necessarily identical with years required to develop silicosis. It would appear, however, that the period for X-ray evidence of silicosis is extending. It was found to be 23 years for pneumatic tool cutters, and 29 years for workers in low exposure occupations. The average years determined for silicosis complicated with suspected tuberculosis is 28 years for cutters and 27 for the other occupations. To what extent individual susceptibility may be a factor as well as gradual reduction in dust concentrations is hard to tell.

Mortality Experience

The association between tuberculosis mortality and granite dust was so strong in the early twenties that there was good reason to expect eventually a marked decrease in incidence from tuberculosis through the reduction of silica dust. The death rate from tuberculosis for cutters rose from 1.5 per 1,000 in 1890–94 to 19.5 in the 1924–26 study. Later data showed that the death rate from tuberculosis for Barre granite workers (previous rates are for cutters only) was 10.6 per 1,000 population in 1926–30 and 16.8 in 1931–35. The corresponding rates for Barre were 3.81 and 3.24, and for Vermont .61 and .48 (9).

Unfortunately, corresponding data for the next 10 years are not available. The crude death rates from tuberculosis in all forms for 1945–49 were calculated to be 1.56 per 1,000 population (using 1950 census populations as a base) for Barre, 1.12 for Washington County, and .30 for Vermont. Although the rates are not exactly comparable, the reduction in mortality from tuberculosis is compatible with reductions in the country as a whole. It would also appear that the influence of exposure to dust on tuberculosis mortality is no longer significant.

Death certificates for 1950 and 1952 through 1955 were reviewed but information was transcribed only on deaths due to silicosis or silico-tuberculosis when either a primary or secondary cause of death. Spread over the 5-year period, 91 deaths from these causes or in combination with other causes were identified with granite workers. Silico-tuberculosis was ascribed as a cause of death for 58; it was the only cause of death mentioned for 50, and in conjunction with heart or chronic diseases for 8. Silicosis alone was mentioned on 3 of the death certificates and on 30 in conjunction with other causes as follows: cancer of the lungs 5, cancer of other sites 3, heart disease and arterio-sclerosis 16, and miscellaneous 6.

Discussion

Insofar as the chest X-ray records show, progress observed thus far in the prevention and elimination of silicosis in the Vermont granite industry is indeed gratifying. Only one new case of silicosis, and this one doubtful, has been diagnosed thus far among men who entered the granite industry since 1937 and are working under conditions of controlled dust. In view of the rapidity with which silicotic lung changes developed not too many years ago among men working under dusty conditions, this finding is certainly a testimony of progress in the suppression of the disease.

Although the present situation is promising, close supervision of the environment and the men should be continued. Employers and employees should not relax their responsibilities in maintaining a safe and healthful working environment. For one thing, the number of men working under complete dust control and over long enough periods is relatively small, so that it may take some time before the adequacy of present-day control methods can be ultimately determined. For another, the prolonged effects of the uncontrolled working conditions will be felt for many years to come.

Moreover, judging from the experience of the Vermont Industrial Hygiene Division, there probably is not a stonecutter who is not exposed intermittently for very short moments to excessive dust concentrations. How often this may happen is impossible to determine. What effect it may have on the production of silicosis, if any, remains to be seen. For these reasons as well as the unique nature of the disease condition, further evaluation of progress needs to be made about 1960 and again in 1965. Should more cases of silicosis among men working in the industry since 1937 be found, they should be carefully investigated and the possible cause determined, so that necessary preventive measures can be instituted. While silicosis is no longer the threat to the existence of the industry that it once was, it will probably continue to occur for some years among workers exposed prior to dust control.

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