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ASBESTOS

Toward A Perspective

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Director's Comment: Asbestos has achieved international notoriety largely because of its reported carcinogenic (cancer-causing) tendencies. A dilemma exists because of a conflict between two issues: 1) negative effects related to public health, and 2) positive public benefits derived from asbestos use. Although positions have already been taken on this subject by many, it is our belief that enough uncertainties exist to encourage further research and discussion. The purpose of this article is to put current knowledge into perspective and to encourage additional analysis. [W.P.C.]

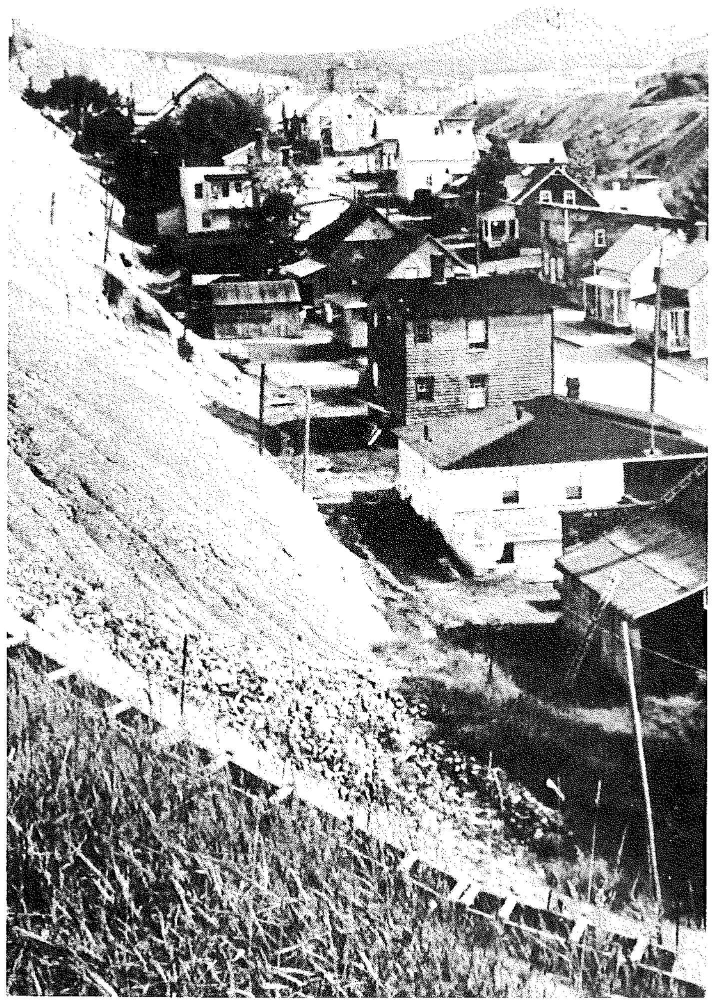
INTRODUCTION

Like the word "snakes", asbestos is not a scientific word. Both are lumping terms encompassing a group of similar, yet different species. Although such terms serve a useful purpose for general identification, they do not acknowledge component parts and, therefore, perpetuate misunderstanding of specific characteristics. Are all snakes identical? Are all fibrous (asbestiform) minerals under the label "asbestos" likely to be identical? Where data exist, is the cause of good science served by not differentiating species and their respective attributes? "No" seems the logical response to each of these queries.

A summary follows of: 1) the nature of the problems related to the use of asbestos, 2) the world-wide geologic distribution of economic deposits of asbestos minerals, 3) the scope and significance of the asbestos industry, 4) highlights of asbestos in Arizona, and 5) health-related considerations. The term "asbestos" will be used in this article to denote the family of commercially exploited mineral fibers.

NATURE OF THE PROBLEM

As civilizations increase in complexity, the number of technical issues projected into the arena of public debate and reaction, especially in democratic societies, also increases. In those technical issues that are delivered to the body politic through the news media (a dominant form of public education), rhetoric may quickly overrun the information base or selectively use data to focus on a specific idea or perceived problem. In such cases, choosing between legitimate concern and overreaction, though difficult at best, seems an essential pursuit, if truth is to be sought rather than emotional response.



Part of a Quebec, Canada mining town nestled among waste piles resulting from the mining and milling of chrysotile asbestos. Photo from *Resources Quebec,* 1980, v. 4, no. 1, p. 18.

The projection of asbestos into the forefront of public awareness over the past decade stems from two conflicting factors: 1) asbestos, a naturally occurring group of earth materials used in a myriad of industrial and domestic products, constitutes the base for an extensive, international mining, milling, and manufacturing industry, and 2) asbestos, under certain circumstances, is a contributing factor in the cause of cancer and other diseases. Thus, there is a diversity of interest in asbestos.

The lack of agreement on what constitutes an asbestos material is a continuing problem. Much disagreement exists over the definition of asbestos, especially as it pertains to occupational health and safety regulations. Defintions vary depending upon those concerned–medical interests, occupational health and safety enforcement agents, mineralogists, lawyers, industrial users, economists, etc. The occupational health and safety standards derive their definition from governmental agencies (U.S. Department of Health and Human Services, NIOSH-OSHA Work Group, 1980).*

The question before the world's health and regulatory establishments is the extent to which the hazards of asbestos outweigh the benefits. On this subject, the Office of Technical Assessment stated in 1981: "Because the Federal Government does not accept a threshhold level for carcinogens, a strict interpretation of these laws would require that risk be entirely eliminated." Obviously, this kind of interpretation creates a dilemma of large proportions. To what extent, as a practical matter, should such laws be enforced? Is there no room for flexibility? Actually, some flexibility is provided to regulatory agencies by Congress through the use of expressions like "unreasonable risks". However, who is to judge what constitutes a reasonable risk? The ideal is to balance risks, costs, and benefits, at the same time being sensitive to equity considerations (i.e., risks may be disproportionately borne by some in order to provide benefits for others).

Can a condition of reasonable risk be attained without debilitating the entire asbestos industry for all time? The answer to this question is encouraged by epidemiological data coming to light which indicate that chrysotile, the principal mineral of the asbestos industry, does not present the degree of risk that attends some of the other commercial fibrous materials.

MINERALOGY AND USAGE

Although there are many naturally occurring elongated minerals that are referred to variously as fibrous, asbestiform, acicular, filiform or prismatic, few occur in deposits suitable for commercial exploitation. Commercial asbestos is generally considered to occur naturally in six forms (see footnote on page 2). It is important to recognize that these six commercial fibrous minerals are not identical in crystal structure, chemical composition, abundance, geologic occurrence, degree of exploitation, etc. Furthermore, human epidemiological data (i.e., incidence, occurrence, and control of disease in a population) suggest that they also are not identical in their disease-causing potential. These commercial fiber types not only differ between species, but also somewhat within species as well. Differences exist in fiber dimension, flexibility, tensile strength, resistance to heat, electrical conductance, specific gravity, and other properties (Shride, 1969).

Each mineral locality tends to have its own set of fiber characteristics suitable for certain, but not all, possible uses. In other words, all occurrences of the same mineral species are not necessarily suited for identical uses. As examples, fiber length is a major factor in grading asbestos for commercial purposes–the longer lengths being more valuable, with the soft fibers worth more than harsh fibers. The longer fibers are valuable because they can be spun or woven into fabrics. Most of the spinning fibers are chrysotile asbestos. Amosite fibers are shorter and are used for various felted insulation products. Lighter weight products can be made with amosite for use in aircraft and ships. Crocidolite has high tensile strength and is acid resistant. Spun or woven crocidolite fibers are used in making fiber cement pipe because they allow free and rapid filtration of fluids that speeds up manufacturing processes (Bowles, 1959).

OCCURRENCE

Major sources of amphibole fibers have been the amosite and crocidolite deposits of South Africa, the crocidolite of western Australia, and the anthophyllite of East Finland (Ross, 1981). Minor occurrences of amphibole-type fibers in the U.S. that have had some production include anthophyllite in Georgia, North Carolina, Idaho, Maryland, and Massachusetts. Tremolite has been mined only in a small way from deposits in South Africa and Maryland. Commercial mining of actinolite is practically unknown. Today, mining of amphibole asbestos is essentially confined to South Africa.

By far, the most important commercial mineral fiber comes from the serpentine type known as *chrysotile*. The two most important world sources of this fiber are the Ural Mountains of Russia and the Appalachian Mountains portion of Quebec, Canada (Table 1), and northern Vermont, U.S.A.

Fiber Type	Continent/Source	Amount Produced
Chrysotile (5,317,000 MT)	Europe	2,775,000
	North America	1,713,000
	Africa	377,000
	Asia	293,000
	South America	101,000
	Australia	58,000
Crocidolite (210,000 MT)	Republic of So. Africa	210,000
Amosite (71,000 MT)	Republic of So. Africa	71,000
	World Total	5,598,000 MT

Table 1. Estimated world asbestos production by fiber type (metric tons), 1978 (data from U.S. Bureau of Mines).

Sixty years ago Arizona led the nation in the production of chrysotile. At that time Arizona chrysotile, formed about 1.2 billion years ago, contained about half as much iron as did the known Canadian (Quebec) chrysotile, a valuable asset

*At present, a widely used definition of asbestos in the United States is included in the proposed regulations and guidelines of "Occupational Exposure To Asbestos", published in the Federal Register by the Occupational Safety and Health Administration (OSHA). In this notice, the naturally occurring amphibole minerals (amosite, crocidolite, anthophyllite, tremolite, and actinolite) and the serpentine mineral (chrysotile) are classified as asbestos if the individual crystal fragments have the following dimensions: length greater than 5 micrometers (microns), maximum diameter less than 5 micrometers, and length-to-diameter ratio of 3 or greater. Any product containing any of these minerals in this size range is also defined as asbestos. [1 meter = 1,000,000 microns; 5 microns = .0002 inches].

A joint National Institute for Occupational Safety and Health and OSHA committee published the following in 1980: "Definition of Asbestos. Having considered the many factors involved in specifying which substances should be regulated as asbestos, the committee recommends the following definition: *Asbestos is defined to be chrysotile, crocidolite, and fibrous cumingtonite–grunerite, including amosite, fibrous tremolite, fibrous actinolite, and fibrous anthophyllite. The fibrosity of the above minerals is ascertained on a microscopic level with fibers defined to be particles with an aspect ratio of 3 to 1 or larger.*"

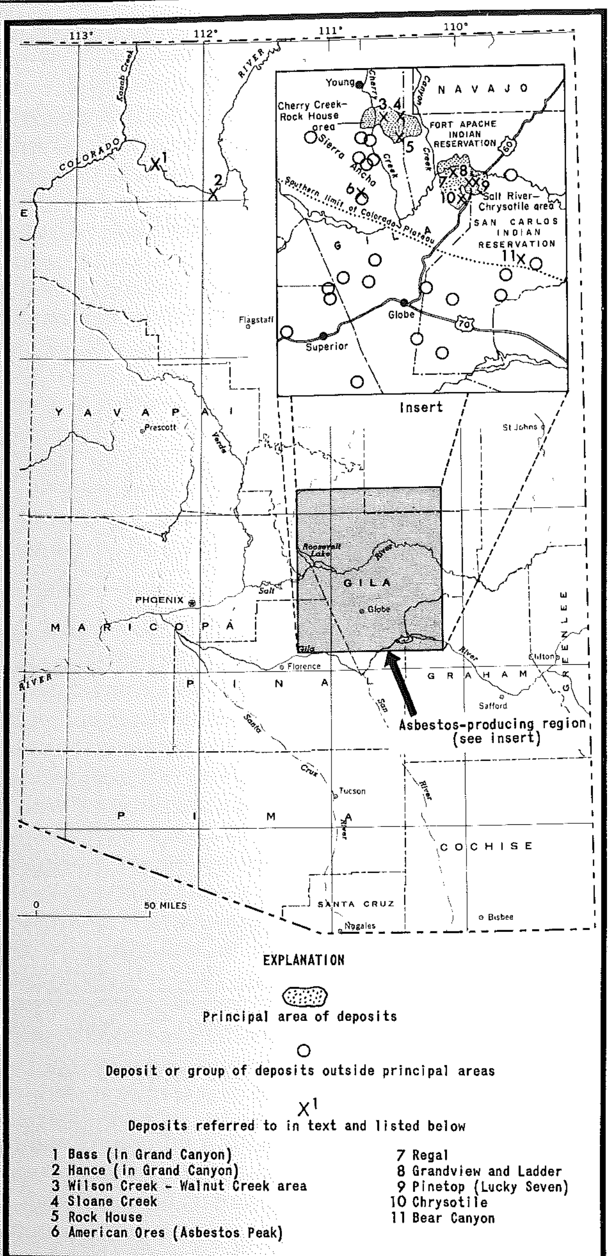


Figure 1. Map of major chrysotile asbestos occurrences in Arizona (from Arizona Bureau of Mines Bulletin 180).

for certain electrical applications. As recently as the 1950s, Arizona chrysotile was the only domestic source of low-iron chrysotile spinning fiber (used in covering electric cables) that met Navy asbestos specifications (Stewart, 1955). The filter market has been the principal outlet for high-grade Arizona chrysotile.

Chrysotile fiber is reported to have been seen in 1869 in the Grand Canyon by members of the Powell expedition (Wilson, 1928). Claims were filed about the year 1900 and a small amount of fiber was mined in 1903. The first of the more famous Gila County occurrences was recognized in 1872. However, additional discoveries were made and the first claims filed in 1913 (Stewart, 1955). In 1914 the Johns-Manville Company acquired the claims and soon became the leading producer in Arizona. Because of this early success, prospecting increased and hundreds of locations were made along the Salt River, Cherry Creek, and in the Sierra Ancha region of east-central Arizona. After World War I, the highest price for the best grade crude chrysotile reached $3,000 per ton, resulting in much early prospecting. In response to this early interest, the Arizona Bureau of Mines published a bulletin called *Asbestos* (Allen and Butler, 1921). Because of a continuing demand for information, another bulletin about Arizona asbestos followed (Wilson, 1928). Major Arizona occurrences of chrysotile asbestos are shown in Figure 1.

PRODUCTION

Although asbestos had been mined as far back as Roman times, the modern industry did not start until the late 1800s. By 1890 the asbestos industry was going strong, with hundreds of commercial applications for fibrous material. Northern Italy was the first region to come into production. However, by 1900 the large South African crocidolite deposits had been opened and the Russian deposits in the Ural Mountains were being mined in large quantity. A few years later, mining of amosite deposits of South Africa was initiated. By 1980 about 100 million MT (metric tons) of asbestos fiber had been mined throughout the world. More than 90 percent of this was chrysotile and about 5 percent amosite and crocidolite (Ross, 1982). The remaining few percent is attributed to the other amphibole fibers, principally anthophyllite.

Amosite from South Africa, crocidolite from Australia, and anthophyllite from East Finland all come from rocks about two billion years in age. South African fiber production presently amounts to about 200,000 MT per year. The production of Australian crocidolite was terminated in 1966 after 138,000 MT had been shipped. The anthophyllite deposits of East Finland were operated continuously between 1918 and 1975, when mining terminated for economic reasons; approximately 350,000 MT of fiber was produced, 230,000 MT of which was exported.

The Quebec chrysotile deposits were discovered in 1877. By 1900 Quebec had already supplied 150,000 MT of fiber; by 1980 nearly 40 million MT had been mined–approximately 40 percent of the world's total mineral fiber production (Ross, 1981). Russia is the world's largest producer of chrysotile today, the Ural area contributing about 2.4 million MT per year.

Other exploited chrysotile deposits are located in the Italian Alps (160,000 MT per year), Cyprus (40,000 MT per year), South Africa (113,000 MT in 1978), Swaziland (48,000 MT in 1978), Zimbabwe (210,000 MT in 1978), and in the Coalinga area of California. Although the California deposits include large near-surface reserves, mining has lagged because of short fiber length and environmental controls (Ross, 1981).

In 1978 Russia produced 2,582,000 MT of chrysotile fiber, 46.1 percent of the world's total fiber output. Canada produced 1,620,000 MT of chrysotile fiber, 28.9 percent of the world total. Thus, in 1978, 75 percent of the world's asbestos production came from just these two regions. In contrast, the U.S. produced 93,000 MT of fiber (chrysotile), less than 1.7 percent of the total. South African amosite and crocidolite production amounted to 281,000 MT or 5 percent of the world fiber output. The remaining 18.3 percent, all chrysotile, is attributed to 15 other countries, the largest shares assigned equally (3.7 percent) to China and Zimbabwe. Only three firms, operating in Vermont and California, are now producing asbestos (chrysotile) in the U.S. Table 1 shows the estimated world production for 1978.

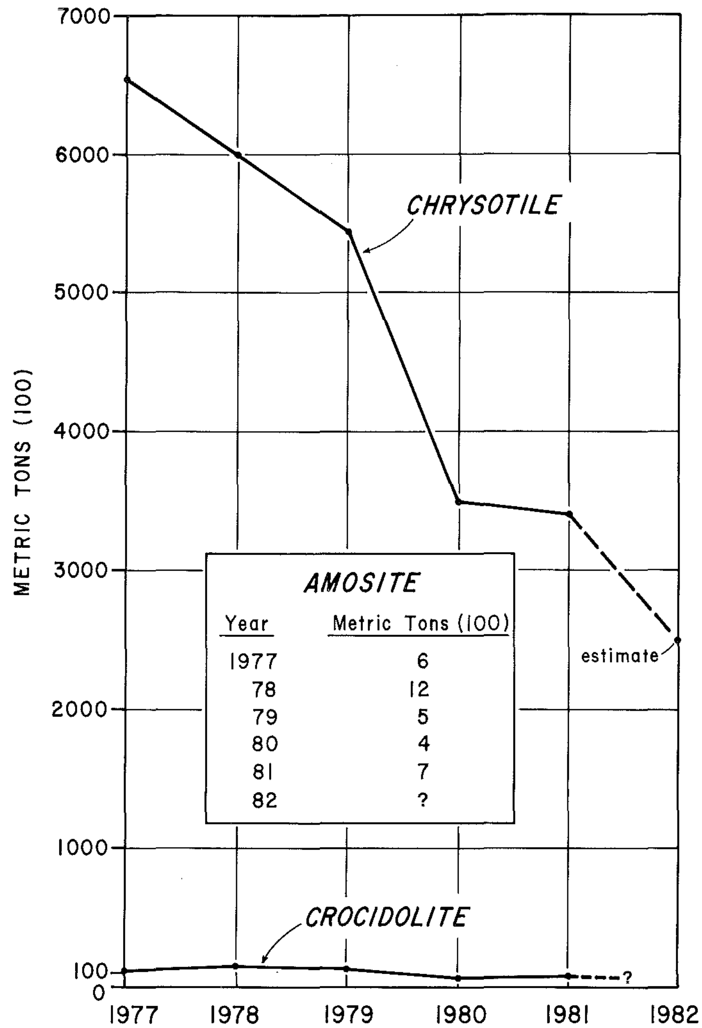
Shride (1969) states that chrysotile asbestos was mined from about 160 deposits in Arizona and that perhaps another 60-70 occurrences are known. In terms of production, Arizona asbestos has, overall, been a small contributor. Shride estimates that total production through 1966 of at least 82,000 MT was valued at about $17 million at the time of sale. Today, the Arizona asbestos industry is inoperative.

CONSUMPTION

The following excerpts about the asbestos industry, as it once was, are taken from Bowles (1959):

> Asbestos furnishes a major raw material for a great variety of essential products, the manufacture of which constitutes a vast industry . . . the United States has developed the greatest asbestos-products industry in the world . . . Domestic mines furnish (in the form of chrysotile fiber) only 6-8 percent of all grades and an even smaller percentage of the important strategic grades.
>
> The procurement of necessary supplies is a problem of world-wide scope, and in every war emergency asbestos assumes top priority among strategic minerals. It is of paramount importance, therefore, that a thorough knowledge should be gained of the composition and properties of asbestos, its uses and requirements for each use, grades and specifications, the degree of essentiality of each application, the nature and extent of sources of supply throughout the world, mine and mill capacity, reserves, transportation, facilities, political and commercial control, world requirements by countries, import and export data, allocation of supplies, fiber beneficiation, possibilities of synthetic asbestos manufacture, use of substitute materials, past war controls, war history, and various other problems that may appear.

The U.S.S.R. has supplanted the United States as the largest consumer of asbestos fiber (Clifton, 1979). U.S. consumption for the years 1977-1982 is shown in Figure 2. Whereas the use of asbestos in developing countries is expanding, Figure 2 indicates a continuous decline in U.S. asbestos consumption since 1977. Clifton (1983) states that the 1982 domestic consumption of about 250,000 MT (over 90 percent supplied by Canada) is the lowest since 1940. He estimates that about 400 firms, centered in the eastern states, are manufacturing asbestos products. In 1982 U.S. commercial uses of fiber included asbestos-cement pipe (37 percent), flooring products (20 percent), friction products (14 percent), roofing products (9 percent), packing and gaskets (6 percent), asbestos-cement sheet (6 percent), and other uses (8 percent). Clifton also suggests that certain domestic market segments may have been permanently lost to substitutes. Although no wholly satisfactory substitutes are available for asbestos in many applications, such as friction needs, much research is underway to evaluate possible alternatives.



AMOSITE	
Year	Metric Tons (100)
1977	6
78	12
79	5
80	4
81	7
82	?

Figure 2. U.S. asbestos consumption by fiber type (100 metric tons), 1977-1982.

HEALTH HAZARDS

That asbestos fibers, under certain conditions of exposure, may cause disabling diseases in humans appears to be well established. Three principal diseases have been attributed to excessive exposure to asbestos fibers: 1) asbestosis, a fibrosis of the lung tissue which reduces the elasticity and function of the lungs, 2) lung cancer, and 3) mesothelioma, a rare cancer of the pleural and peritoneal membranes. Nearly all of the asbestos-related diseases have occurred in occupational groups–those concerned with mining and milling of asbestos, the manufacture of asbestos-containing products, and the application and removal of insulation materials containing asbestos fibers. However, some non-occupational asbestos-related disease has been documented and is summarized later.

During the turn of the century when the use of asbestos fibers was increasing due to rapid expansion of product lines, the control of dust created by certain operations was not perfected. It is known that in some textile manufacturing operations, such as carding, spinning, and weaving of asbestos fibers, dust concentrations were so high that a person could not see beyond an arm's length. After many years of this type of exposure, some employees developed a pulmonary disease that was named asbestosis. Upon recognition of this affliction, dust control measures were initiated that significantly reduced the incidence of asbestosis.

The first suggestion of a causal relationship of exposure to asbestos fibers and lung cancer was proposed in the mid-1930s (Lynch and Smith, 1935). It was also recognized that there was a long time lag between first exposure and onset of disease. As with asbestosis, the control of exposure resulted in a marked decrease in the incidence of lung cancer.

The association of exposure to asbestos fibers and mesothelioma was not given serious consideration until after

1960 when 33 cases of mesothelial malignancies were reported in a crocidolite mining population in South Africa (Wagner and others, 1960). This disease appeared many years after initial exposure.

Generally, asbestos-related diseases appear in asbestos workers only after many years have elapsed since first exposure. A significant increase in the lung cancer death rate appears 10-14 years after first exposure and peaks at 30-35 years. The mesothelioma death rate becomes significant 20 years after first exposure, but continues to climb even after 45 years have elapsed. The asbestosis death rate becomes significant 15-20 years after first exposure and apparently peaks at 40-45 years (Selikoff and others, 1980). It is to be emphasized that these cited, generalized statistics are based upon studies of workers who were exposed daily to various fiber types as part of their work environment. The significance of exposure levels of the different fiber types, over time, needs to be addressed if precision and a guiding perspective are to be gained.

Risk

The determination of asbestos risk can be approached in two ways: 1) tests on animals, and 2) observations on humans exposed to asbestos dusts in mines and mills, and various plants and workplaces where these particular fibers are involved. The argument is made that animal studies are essential because the time required to study humans renders most direct studies impractical. The only reliable study of humans involves case histories with statistical data assemblages. A result is said to be positive when it reveals an *excess* of mortality that is caused by the agent under study. (An *excess* is that amount beyond what is statistically expected in a population not exposed to the risk.) Positive epidemiological results are taken by agencies as strong evidence of carcinogenicity, whereas a positive bioassay (animal test) is taken as evidence that a substance is a *potential* human carcinogen. Apparently, agencies specify stringent requirements with which to weigh negative epidemiological data against positive animal information.

Carcinogenicity of asbestos fibers has been studied by exposing laboratory animals to fibers by the following methods: intratracheal injection, intraperitoneal injection, intrapleural injection, ingestion, and inhalation. With the exception of inhalation, and ingestion to some extent, the foregoing routes of exposure are not likely in humans. In addition, the quantity of asbestos required to produce these effects in laboratory animals, by any of these routes of exposure, is high relative to dosages experienced by humans in occupational environments.

A report dealing with airborne asbestos was prepared by the Committee on Biological Effects of Atmospheric Pollutants (National Research Council, 1971), and information derived from their assessment of animal studies may be worth noting:

> Asbestotic pulmonary fibrosis has been produced experimentally in various species of animals, including rats, guinea pigs, hamsters, rabbits and monkeys. In many of the studies, the disease resembled early asbestotic development in man . . . Diffuse fibrosis has also been produced, but to do so it was necessary to use very high concentrations of asbestos dust and long periods of exposure or observation after exposure . . . Lung cancer from chrysotile dust has been produced experimentally in rats and in mouse lung implants. Other investigators who used different methods for introducing the dust did not find lung cancer in animals they studied... Rats whose lung clearance had been artifically impaired had twice the lung cancer rate of animals with normal clearance... cancer of the pleural surface (mesothelioma) has been reported in rats and hamsters that received intrapleural injections of the three most common types of asbestos. The amounts of asbestos dust introduced into the thoracic cavity were very large, and translation of results to human inhalation of asbestos is uncertain.

As already indicated, disease incidence increases significantly among various asbestos trades workers. Most of these are men who most likely handled several types of asbestos fibers during their working careers. In contrast, miners and millers tend to be exposed to only one form of fiber. This latter category, then, provides some opportunity to isolate the effects of individual fiber forms on health. More about this later.

Lungs of persons in urban and rural non-occupational settings have been shown to contain "asbestos" fibers. Many of these fibers, or bodies, are probably derived from the burning of leaves and from plant products, such as paper, wood, and coal, man-made fibers, talc used generously as a body dusting powder (which may contain tremolite), graphite, hornblende, diatomaceous earth and carborundum (National Research Council, 1971; Cooper, 1967). That thousands or even millions of fibers are present in most human lungs has been recognized since the turn of the century. Although many urban areas contain measurable asbestos fiber counts in the ambient air, epidemiological study indicates that there are no unusual health problems attributed to breathing chrysotile fiber in a non-occupational setting (Ross, 1982).

In many epidemiological studies, "asbestos" is the common denominator and specific fiber types are not considered. Some feel strongly that such lumping serves to mask the probability that the various fibers differ in their disease-causing tendencies in humans (Ross, 1982; Rutstein, 1982). This distinction, if valid, should be viewed with the knowledge that chrysotile fiber is the overwhelming contributor to asbestos production the world over, besides being the only fiber mined commercially in the U.S. However, amosite and crocidolite, though normally minor contributors, were heavily used in certain war-related industries during World War II.

Malcom Ross (1982), a physical chemist and geologist-mineralogist with the U.S. Geological Survey, has reviewed and analyzed asbestos-related data from 110 published sources from around the world. His primary interest was to survey asbestos-related disease in all aspects of the industry and assess *non-occupational* risks of fibrous minerals. Following are some of Ross' conclusions:

> 1) Non-occupational exposure to chrysotile asbestos, despite its wide dissemination in urban environments throughout the world, has been shown by epidemiological studies to be of no recognized health significance. If chrysotile asbestos were hazardous to health, the women of Thetford Mines, Quebec (where over 20 million MT of chrysotile asbestos has been mined), would be dying of asbestos-related diseases; yet this has not occurred (see cover photo). The health studies completed in Canada suggest that populations

can safely breathe air and drink water that contain significant amounts of chrysotile fiber.

2) Crocidolite asbestos shows an entirely different fiber-dose disease-response relationship from that observed for chrysotile asbestos. Health studies of those exposed only to crocidolite show that it is much more hazardous than chrysotile, perhaps 100-200 times more hazardous with respect to mesothelioma. The danger of crocidolite dust is particularly emphasized by the many mesothelioma deaths occurring among the residents of the crocidolite mining districts of the Cape Province, South Africa, where the exposure occurred in a non-occupational setting. Such mortality is practically unknown among residents of the chrysotile mining localities of Quebec. Control of crocidolite dust, particularly in mines and mills, presents a considerable engineering problem in that dust levels at or below the 1969 British Standard of 0.2 fibers/cm^3 (1 cm^3 = one cubic centimeter or one milliliter) virtually cannot be achieved (Simpson, 1979, p.74).

3) The hazards of amosite asbestos are more difficult to assess. The amosite factory employees of Paterson, New Jersey, who worked under very dusty conditions during World War II, have experienced excess mortality due to lung cancer, asbestosis, and mesothelioma. In contrast to these factory workers, amosite miners, and millers elsewhere in the world, at least with regard to mesothelioma, do not appear to be at much risk. This suggests that dust controls are possible which can greatly reduce or prevent the occurrences of asbestos-related diseases in amosite workers.

4) The fear caused by statements and implications to the effect that "one fiber can kill" and by the apparently exaggerated predictions of the amount of asbestos-related mortality expected in the next 20 or 30 years, has generated much political pressure to remove asbestos from our environment and to greatly reduce or even stop its use. An example of this is the concerted effort in several industrial nations, including the United States, to remove asbestos from schools, public buildings, homes, ships, appliances, etc. This is being done, even though most asbestos in the U.S. is of the chrysotile variety, and even though asbestos dust levels in schools, public buildings, and city streets are much lower than dust levels found in chrysotile mining communities where no asbestos-related disease has been reported in the non-occupationally exposed residents. The impetus for these costly removals and appliance recalls (hair dryers, for example) apparently comes from capitalizing on the "one fiber can kill" concept. Not only is this program costly–it could be dangerous if the removal of crocidolite asbestos is not accomplished with great care. In most cases, asbestos coatings and insulation, where necessary, can be repaired at no risk and at a fraction of the cost of complete removal.

Rutstein (1982) comments on relative health hazards of the various fiber types:

> Outside the U.S., particularly in Great Britain, it is widely believed that crocidolite is much more dangerous than chrysotile, and, further, that much of the data suggesting that asbestos is harmful is based on the effects of crocidolite, and perhaps, amosite, but not on the much more widespread chrysotile . . . Let us now consider why there was an asbestos scare. Irving Selikoff of the Mount Sinai School of Medicine continues to lead in advocating the dangers of asbestos. His classic studies (1973) of the asbestos-insulation workers of New Jersey show quite clearly that they were indeed much more susceptible to asbestosis and various cancers. Lung cancer was prevalent, especially if the workers smoked cigarettes. Most of the asbestos workers in Selikoff's studies were probably exposed to more than just the chrysotile variety of asbestos. Crocidolite was particularly favored for insulation on ships. However, the interpretation of the epidemiological data did not stress distinguishing between health effects attributable to different mineral species, but only to "asbestos".

Why should these fiber types act differently? Perhaps because they have contrasting physical and chemical attributes. For instance, chrysotile fibers curl into spirals, whereas the amphiboles (crocidolite and amosite) develop straighter, more needle-like fibers, and appear to penetrate more deeply into the terminal air sacs of the lungs (Figure 3). Chrysotile is a magnesium silicate, amosite is an iron-magnesium silicate, and crocidolite is a sodium-iron-magnesium silicate. Their solubilities and resistance to chemicals are known to differ.

Recently, the authors attended a talk (January 21, 1983) about asbestos-related disease, presented by Margaret Becklake, M.D. (McGill University, Canada) at the University of Arizona medical center. She restated her belief that chrysotile eventually dissolves in the lungs and therefore does not continue to accumulate like the amphibole fibers do. Previously, she had reported the following (Becklake, 1982):

> Subsequent studies have also strengthened the evidence that fibers dissolve out of the lungs over time, the loss occurring preferentially in chrysotile fibers. Thus, though chrysotile accounts for the bulk of commercial use and hence human exposure, it is the amphiboles that constitute the core of the majority of asbestos bodies found in human lungs, even in those known to have had occupational exposure to chrysotile (Warnock, 1979; 1980; 1981) . . . All these findings strengthen the evidence that chrysotile is cleared more readily from the lungs than other fibers . . .

Perhaps the best available information on chrysotile fiber exposure-risk levels comes from studies in Canada, the source of much of the chrysotile fiber used in the U.S. As an example, Ross (1982) reports:

> Epidemiological studies of the chrysotile asbestos miners and millers of Quebec, undertaken by medical researchers in Canada, show that for 3,105 men exposed for more than 20 years to chrysotile dust averaging 20 fibers/cm^3, the total mortality was less than expected (620 observed deaths, compared to 659 expected deaths). Risk to lung cancer was slightly increased–48 deaths observed and 42 deaths expected. Exposures to 20 fibers/cm^3 are an order of magnitude greater than those experienced now (generally less than 2 fibers/cm^3); thus chrysotile miners working a lifetime under these present dust levels should not be expected to suffer any measurable excess cancer.

How much is 20 fibers/cm^3? According to Rutstein, at an allowable limit of 2 fibers/cm^3 of air (over an 8-hour industrial environment workday), the average worker could easily inhale 7 million fibers per day. Thus, he too questions the incon-

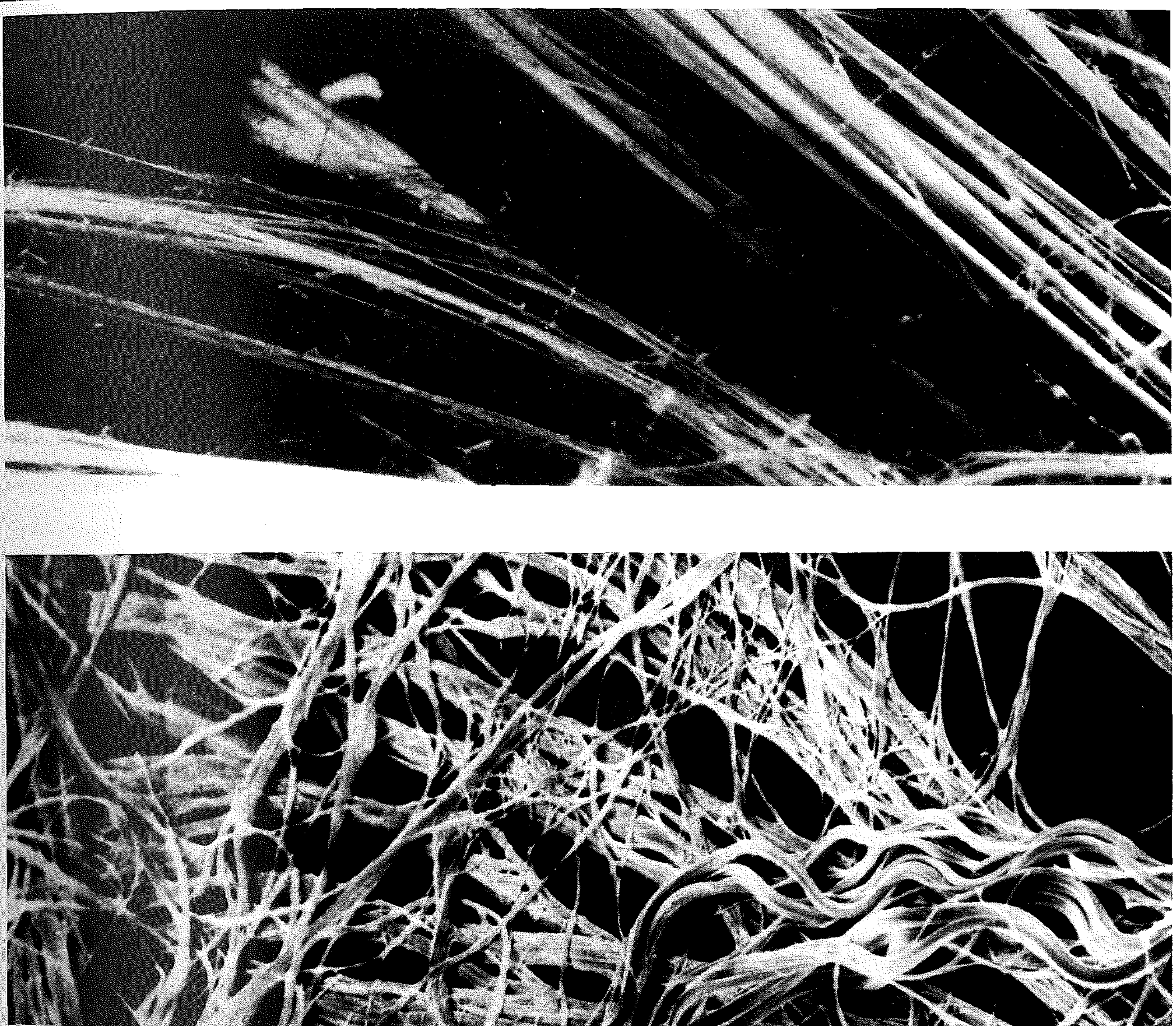


Figure 3. Crocidolite (straight fibers) from South Africa and chrysotile (wavy fibers) from Globe, Arizona, viewed through a scanning electron microscope. The thinner fibers are less than .0004 inches thick. Photos courtesy of the U.S. Geological Survey.

sistency revealed in permitting the inhalation of several million fibers on the one hand and promoting the "one fiber can kill" concept on the other hand.

Clifton (1983) reports that the United Kingdom Health and Safety Commission decided to implement tighter controls over asbestos exposure. The new limits, which were effective January 1, 1983, are: chrysotile, one fiber per milliliter of air (1 f/ml); amosite, 0.5 f/ml; and crocidolite, 0.2 f/ml. [chrysotile was lowered by 1 f/ml and the others are unchanged.]

What is known of the asbestos-related mortality rate in the U.S. and what are the estimates for the future? If one looks over the data, it becomes obvious that firm numbers do not exist. Ross points out that former Secretary of the U.S. Department of Health, Education and Welfare, Joseph A. Califano, reported figures in a 1978 speech that translate into 76,000 cancer deaths per year due to asbestos. The data came from medical scientists associated with the National Institutes of Health. In 1980, Dr. Irving Selikoff stated at a press conference that 20,000 U.S. asbestos workers would die each year for the next 40 years of "excess disease". Subsequently, in 1981 Dr. Selikoff, through a press release to the Associated Press, stated that 10,000 American workers are dying each year because of asbestos exposure. He did not supply a data source for these estimates.

Ross asks if any of these numbers are correct. Using existing statistics from Vital Statistics of the United States dealing with mortality factors, asbestosis deaths in the nation for the period 1967-1977 are seen to average 41 per year. However, Ross cites data indicating that deaths due to this cause are underreported, therefore adjusts the average figure to 88. Using this number in combination with asbestos-related epidemiological statistics, Ross estimates the likely annual mortality due to lung cancer and mesothelioma. Combining these, his estimates for total annual asbestos-related mortality range from 522-587. Furthermore, he thinks that asbestos-related mortality will peak between 1980 and 1985, 35 to 40 years after the large World War II shipyard employment.

In regard to the estimation of risk in human non-occupational exposure to asbestos, the National Research Council's

Committee on Biological Effects of Atmospheric Pollutants (1971) wrote:

> The most important question in the case of persons with non-occupational exposures to asbestos is whether there is an increased risk of malignancies. Industrial experience indicates that there is no likelihood of significant asbestosis in non-occupational exposure. The major potential for risk appears to lie in those with indirect occupational contacts, household contacts, or residence in the immediate neighborhood of asbestos sources; and even there, the actual risk is poorly defined. But the fact that there appears to be a gradient of effect in such groups suggests that there are levels of inhaled asbestos without detectable risk. It is not known what range of respirable airborne asbestos fibers will ultimately be found to have no measurable effects on health. At present, there is no evidence that the small numbers of fibers found in most members of the general population affect health or longevity.

More recently, in response to a question concerning non-occupational exposure to chrysotile asbestos in Canada (see cover photo), Dr. Becklake stated the following (personal communication, 1983): "A mortality study has been carried out referring to residents of the asbestos mining towns of Quebec. No significant excess general mortality was shown in women. The excess in men was thought to be related to occupational exposure." Asked if society should ban all forms of asbestos use, Dr. Becklake commented, "We humans live with many dangerous materials and are able to control others; why not this one?"

Globe, Arizona, has been in the news periodically, most recently because of its association with EPA's Superfund. A mobile home park is situated on land, parts of which were once dedicated to the processing of chrysotile asbestos. At question is the health risk. A dilemma prevails because there are no factual scientific data that clearly define the relationship between all possible exposure levels of chrysotile asbestos and risk. As already pointed out, high *occupational* exposure levels can be risky, whereas there is no evidence of significant risk at levels frequently characterized as *non-occupational*. However, how should the possible exposure levels at the mobile home park be characterized? Might they be high, low or intermediate, depending upon several variables? Is living there likely to be more or less hazardous than living in the chrysotile mining and milling centers of Quebec, Canada? Because of a paucity of accurate, scientific data, and in spite of efforts to gather more, answers to such questions remain largely subjective and somewhat arbitrary. Although this is the nature of the problem that confronts the various state and federal agencies, decisions must nevertheless be made. In the absence of definitive, scientific health-risk data, decisions on final actions will inevitably be based upon economic-political considerations.

Substitutes

In a report of the Advisory Committee on Asbestos, Health and Safety Commission of Great Britain, the following statement is made regarding substitutes for asbestos (Simpson, 1979, v.1, p.69):

> As a general principle we take the view that control of any useful but hazardous material is preferable to the ultimate sanction of prohibition. It is very easy to say that a dangerous substance or process should be banned and to hope that that will solve the problem. In our view, this is a gross over-simplification of a complex equation of interlinked factors. It ignores the possibility that prohibition of a particular substance may directly result in an increase in health or safety risks, for example from fire, which the use of that substance currently prevents or reduces. It also ignores the implications of statutorily enforcing substitution by materials or substances that presently appear to be suitable but may at a later date be found to constitute a risk to health. The social and economic consequences of the possible closure of factories using the original material or process need be taken into account.

Until recently, the U.S. has been the largest producer of asbestos products, mostly from imported fiber. The three principal natural fibers that enter into commerce–crocidolite, amosite, and chrysotile–have physical and chemical characteristics that are difficult to duplicate by substitution. As a consequence, substitutes tend to perform in an inferior way. The costs (including health and safety), imposed on society because of inferior performance, are not yet known.

CONCLUSIONS

The mining, milling, processing, and fabrication of a family of naturally occurring fibrous asbestos minerals, especially chrysotile, is world-wide in scope. The overall benefits of asbestos products to society at large are incalculable. Because of adverse publicity, the "hazards" of asbestos seem to preclude benefits derived from its use.

The specter of disease, especially cancer, has been attached by some to the exploitation, processing, use, and even general occurrence of asbestos. How serious is the asbestos-related disease threat? Judging from the data cited in this perspective-seeking report, the hazard seems to depend principally on two points: 1) the specific mineral, and 2) exposure level.

The nature of the asbestos problem is recognized and it is believed that present technology is capable of controlling occupational chrysotile exposures to levels that are not anticipated to result in excess disease. Studies of the non-occupational health risk of chrysotile suggest no detectable excess disease; therefore, the prevailing generalization that *any* non-zero exposure to chrysotile can cause serious medical problems should be questioned.

These data, though not finally definitive, nevertheless support the contention that failure to discriminate between the various fiber types and exposure levels is scientifically and practically inappropriate. Thus chrysotile may have become the victim of "guilt by association", having been lumped with the more dangerous minerals, crocidolite and amosite, under the general term, "asbestos".

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ERRATA

Two figures in the Technical Report prepared by Reynolds and Keith, *Geochemistry and Mineral Potential of Peraluminous Granitoids* (December 1982, v. 12, no. 4, p. 5), were mislabeled. Figures 1 and 3, reprinted below, have been corrected. The positions of the labels "alkaline" and "subalkaline" have been reversed, as shown here.

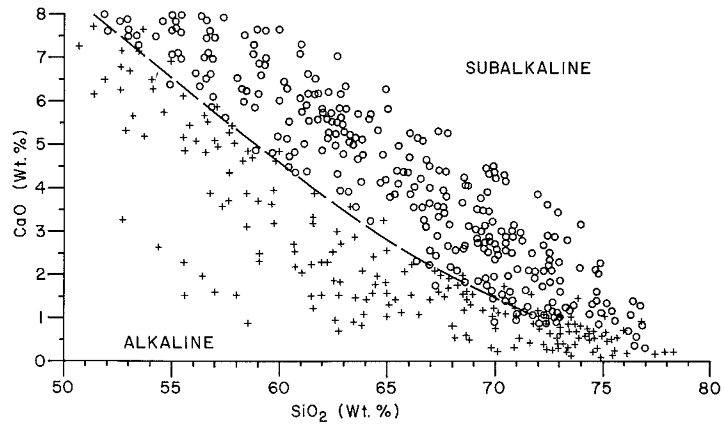

Figure 1. SiO_2 versus CaO variation diagram for metaluminous-suite igneous rocks of known alkalinity. Dots represent calc-alkalic and calcic rocks; crosses indicate alkali-calcic and alkalic rocks (classifications according to Peacock, 1931).

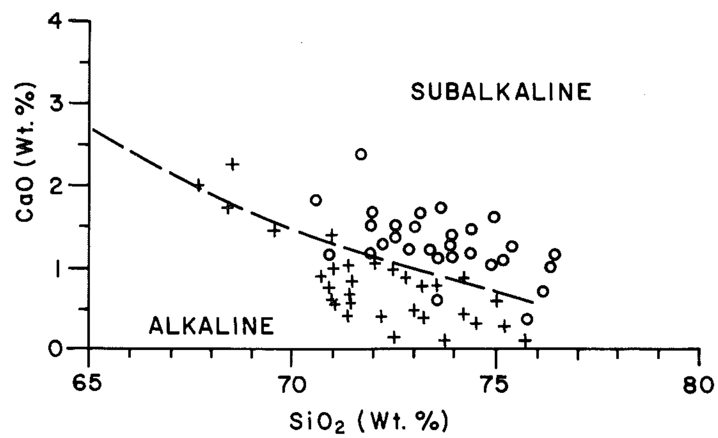

Figure 3. SiO_2 versus CaO variation diagram for peraluminous granitoids of Arizona (o) and the Hercynian belt of Europe (+).

NEW PUBLICATIONS

Roadside Geology of Arizona, by Halka Chronic; Mountain Press Publishing Co. (Box 2399, Missoula, MT 59806; 406/728-1900), 1983, 314 p. Aspects of Arizona's geology and diverse landscapes that can be seen from the highways are presented in this "guidebook" as an introduction to those with little or no geologic training. $9.95

Checklist of Arizona Minerals, by Raymond W. Grant, Mineralogical Society of America (PO Box 902, Phoenix, AZ 85001), 1982, 78 p. Describes physical properties of 640 known minerals in Arizona; lists the state's minerals according to Dana's system. ($6 + shipping) $7.00

ARIZONA MINERAL PRODUCTION FOR 1981

by Jon E. Spencer

Arizona maintained its standing as the leading copper producer in the U.S., producing almost 68 percent of total U.S. copper production. Copper output reached 1,040 thousand metric tons, surpassing the previous high record achieved in 1979. See Table 1 for copper-mine production in Arizona.

Pima County, Arizona's number one copper-producing county, produced more than three times as much copper as the state of Utah, the second largest copper-producing state. Arizona ranked second in molybdenum and silver production, and fourth in gold production. These metals were recovered primarily as byproducts of copper production (See Table 2).

1981 RANK	1980 RANK	MINE	COUNTY	OPERATOR
1	1	Morenci	Greenlee	Phelps Dodge Corp.
2	5	San Manuel	Pinal	Magma Copper Co.
3	4	Ray Pit	Pinal	Kennecott Copper Corp.
4	3	Twin Buttes	Pima	Anamax Mining Co.
5	7	Pinto Valley	Gila	Cities Service Co.
6	2	Sierrita	Pima	Duval Corp.
7	6	Bagdad	Yavapai	Cyprus Bagdad Copper Co.
8	8	Inspiration	Gila	Inspiration Consolidated Copper Co.
9	9	Eisenhower	Pima	Eisenhower Mining Co.
10	13	Magma (Superior)	Pinal	Magma Copper Co.
11	10	Pima	Pima	Cyprus Pima Mining Co.
12	11	New Cornelia	Pima	Phelps Dodge Corp.
13	—	Mission	Pima	ASARCO Inc.
14	—	Silver Bell	Pima	ASARCO Inc.
15	15	Sacaton Unit	Pinal	ASARCO Inc.

Table 1. Leading copper-producing mines in Arizona, in order of output

Detailed statistics on Arizona nonfuel mineral production have been recently published in the Arizona chapter of the U.S. Bureau of Mines' *Minerals Yearbook* for 1981. Additional information can be obtained from Lorraine Burgin, State Minerals Specialist for Arizona, with the U.S. Bureau of Mines in Denver.

MINERAL	1980 QUANTITY	1980 VALUE (thousands)	1981 QUANTITY	1981 VALUE
Copper (metric tons)	770,119	$1,738,908	1,040,813	$1,953,142
Molybdenum (thousand pounds)	35,668	341,965	35,808	254,345
Sand and Gravel (thousand short tons)	24,399	73,773	22,679	169,855
Silver (thousand troy ounces)	6,268	129,363	8,055	84,728
Gold (troy ounces)	79,631	48,779	100,339	46,120
Lime (thousand short tons)	514	23,904	538	29,913
Stone–crushed (thousand short tons)	6,205	24,780	6,315	26,263
Gem stones	——	3,100	——	3,250
Gypsum	209	2,017	213	2,594
Clays (thousand short tons)	151	1,151	148	1,105
Lead (metric tons)	165	152	993	800
Pumice (thousand short tons)	9	13	1	3
Combined value of asbestos, barite (1981), cement, perlite, pyrites, salt, tungsten, and vanadium	——	83,037	——	93,009

Table 2. Production and value of metallic and non-metallic minerals in Arizona

(data from U.S. Bureau of Mines' *Mineral Yearbook,* 1981)

Arizona Surpasses U.S.S.R. in Copper Production

Arizona is a copper producer of international significance. Statistics from the copper chapter of the Bureau of Mines' *Minerals Yearbook* for 1981 indicate that Chile was the only nation that produced more copper than Arizona (Figure 1). Only five nations–Chile, the Soviet Union, Canada, Zambia, and Zaire–produced more copper than Pima County (Figure 2). Due largely to Arizona's copper output, the United States was the world's number one copper producer, with total production in 1981 of 1,538 thousand metric tons.

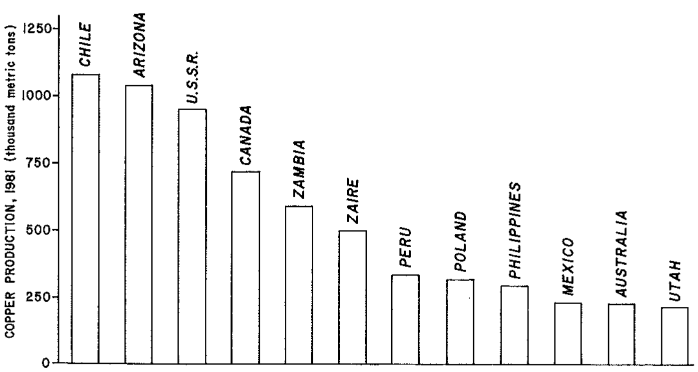

Figure 1. Copper Production in 1981: States and Foreign Countries.

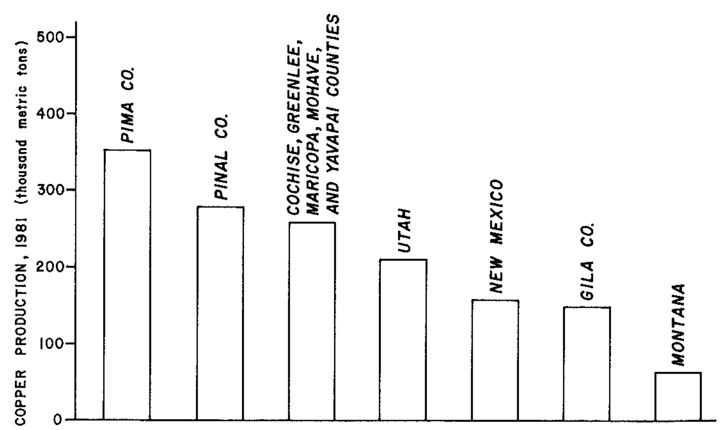

Figure 2. Copper Production in 1981: Arizona Counties and Other States

BUREAU PUBLICATIONS

Geothermal Energy in Arizona, a report prepared by Claudia Stone and James C. Witcher, has been placed on open file at the Arizona Bureau of Geology and Mineral Technology.

This is the final report on work done by the Bureau under contract with the U.S. Department of Energy, Division of Geothermal Energy (Contract No. DE-FC07-79ID12009), between May 1977 and August 1982.

The report brings together in a single volume current knowledge of and basic data on potential geothermal resources in Arizona. In addition it includes results of preliminary investigations for each area of the State in which geothermal assessment was made.

Most of the geothermal waters that have been identified in Arizona are in the low (less than 90° C) to moderate (90°–150° C) temperature range. The most likely potential uses for waters in this temperature range are for direct-heat (nonelectric) applications such as space heating and cooling, agriculture and aquaculture production, and industrial processes.

Open-File Report 83-12, "Geothermal Energy in Arizona", may be examined at the Arizona Bureau of Geology and Mineral Technology library. Copies are also available for purchase for $20.00 (over-the-counter) or $24.00 (by mail order). Make checks payable to the Bureau of Geology and Mineral Technology, 845 N. Park, Tucson, AZ 85719. Payment must accompany mail order request.

NOTICE

Response to the State Geologic Map of Arizona (1969) was so great that the Bureau's stock has been depleted. More maps have been requested from the U.S. Geological Survey, which is currently arranging for the reprint. The Bureau of Geology and Mineral Technology will announce in a later issue of *Fieldnotes* when the state map will again be available for purchase.

ANNOUNCEMENTS

Cartographers, illustrators, drafters, and researchers — consider revising your county base maps of Arizona. "La Paz" (meaning 'peace') is the state's newest county, in the area which was formerly northern Yuma County. Specs may be obtained by writing the Yuma County Courthouse at 168 S. 2nd Ave., Yuma, AZ 85364.

The Department of Interior has awarded ten contracts to eight contractors for the collection of data on foreign mineral deposits. The data will include name, ownership, and location of each deposit; ore tonnage and grade figures; a description of the orebody and extraction system; staffing and energy requirements; and a detailed cost analysis. An extensive data base on the availability of minerals will emerge as the Minerals Availability System (MAS) is implemented.

One of the contractors is located in Tucson, AZ — Pincock, Allen & Holt, Inc.; the firm has been awarded $179,836 for the study of beryllium, lithium, zirconium, mercury, and molybdenum deposits.

Arizona Oil & Gas Conservation Commission

1982 Activity Report

A.K. Doss, Executive Director

Another busy year for oil and gas exploration and related activities in Arizona has concluded. Two of the wildcats were "near misses" and one other wildcat logged oil and gas shows that were good enough to result in a very expensive attempt to complete the hole as a producer. The following table indicates a comparison of activities for the last 3 years.

	1980	1981	1982
1. Number of drilling permits issued	14	73	48
2. Total number of wells drilled	8	51	42
3. Total footage drilled	32,775	65,400	76,708
4. Number of dry holes	7	9	16
5. Number of oil producers	0	6	1

As can be seen there were fewer wells drilled in 1982, but the amount of footage drilled was considerably more than in 1981. Numbers 4 and 5 above show that there were substantially more wildcats drilled in 1982 (17) and more than double the number (7) drilled in 1980. The predicted 100,000 feet drilled for 1982 was not reached; this was undoubtedly the result of budget cutbacks in practically all the oil companies. The ratio of producers to dry holes should improve measurably for 1983 because Kerr-McGee plans to drill seven infill wells in the Dineh-bi-Keyah field and Mountain States plans additional drilling in the Teec Nos Pos field. The one producing well was drilled by Mountain States as their #12 Navajo-0, a stepout in the Teec Nos Pos field.

Brooks Exploration drilled a 7,000-foot wildcat in the strip country about halfway between Fredonia and Colorado City (Short Creek). They ran a drill stem test (DST) between 570 feet and 642 feet and recovered 70 feet of oil-cut mud and 20 feet of free oil. The oil was analyzed as 29° gravity API. The oil formation is tentatively identified as the Schnabkaib member of the Moenkopi Formation. Follow-up drilling could result in a field discovery similar to the old Virgin field type just across the state line in Utah. The other "near miss" is the Gustin #1-24 Federal, located one mile north of Chambers. This well has sweet gas and oil on the pits at approximately 1,358 feet (formation unidentified). The oil on the pits was a high-gravity sweet crude. The operator has installed a small pumping unit and, at last report, was pumping water. Follow-up drilling is planned around this well.

Fifteen geothermal gradient holes were drilled by Phillips Geothermal Division in the Agua Caliente and Alpine areas. These holes accounted for about 6,000 feet of drilling.

At the present time, the following estimated amounts of acreage are under active oil and gas leases: 1) Federal 10,500,000 acres; 2) State 2,500,000 acres; and 3) Private 5,000,000 acres.

Oil and Gas Revenues to Arizona

1. Advalorum taxes (10¢/$ on gross sales of oil and gas)	$1,300,000
2. Sales tax (2% of the gross sales of oil and gas)	400,000
3. Rentals to the state (state lands and one-half on federal lands	8,000,000
4. Commercial sales (rent, food, clothing, fuel, trucking charges, recreation, etc.), conservatively estimated	600,000
Total Revenues	$10,300,000

The prognosis for 1983 is that of another year of continued high drilling and exploration activity and an improved possibility of finding the first discovery of oil and gas off the Indian Reservation.

Arizona Bureau of Geology and Mineral Technology Annual Report for 1982

The Arizona Bureau of Geology and Mineral Technology, known as the Arizona Bureau of Mines until 1977, consists of a Geological Survey Branch and a Mineral Technology Branch. The Geological Survey Branch is the state geological survey. The Bureau is administered by the Arizona Board of Regents and is supervised by the President of the University of Arizona or his designate, traditionally the Dean of the College of Mines.

The Bureau is defined by statute as a scientific, investigative, and information agency whose purpose is to do research and provide information about the geologic setting, mineral and energy resources, mineral technology, and the impact of "things geologic" in Arizona. Information and research projects and activities during 1982 are summarized below.

INFORMATION AND ASSISTANCE. Information and assistance are provided by Bureau scientists, upon request, to the legislature, governmental agencies, industry, and the public. In addition, the Bureau publishes, sells, and distributes geologic maps and reports; maintains a library that contains published and unpublished maps and reports; maintains a repository of rock cuttings and cores, and publishes a quarterly newsletter, *Fieldnotes*.

Bureau staff commonly work with staff members of other state agencies, including the Land Department, Oil and Gas Conservation Commission, Department of Mineral Resources, Department of Transportation, Department of Health Services, Department of Water Resources, Office of Economic Planning and Development, Energy Office, and others.

RESEARCH AND DATA COLLECTION. Projects completed during 1982:

1) *Geothermal Resources Map of Arizona*, 1:500,000 scale, published as Map 15;
2) *Index of Published Geologic Maps, 1903-1982*, 6 sheets at 1:1,000,000 scale, published as Map 17;
3) *Geothermal Resources in Arizona, A Bibliography*, published as Circular 23;
4) *Arizona Earthquakes, 1776-1980*, published as Bulletin 193;
5) *Geologic Map of the South Mountains*, 1:24,000 scale;
6) *Geologic Map of Western Harquahala Mountains*, 1:12,000 scale;
7) *Quaternary Geologic Map of Arizona*, 1:250,000 scale;
8) Entry of mineral production and occurrence data for Arizona into Computerized Resource Information Bank (CRIB);
9) Geologic data compilation and assessment of mineral potential in selected wilderness study areas in Safford district (Bureau of Land Management).

Projects in Progress: 1) map showing mineralized districts in Arizona, 1:1,000,000 scale; 2) report on the geology of South Mountains; 3) outcrop map of rocks of Laramide age, 1:1,000,000 scale; 4) report on geologic occurrence of uranium in Arizona; 5) map of Quaternary faults in Arizona, 1:500,000 scale; 6) map of late Cenozoic faults and volcanic deposits, 1:500,000 scale; 7) geologic maps of Phoenix, Tucson, and Nogales on 1° × 2° sheets, 1:250,000 scale; 8) report and map on the geology and mineral resources of Little Harquahala and Granite Wash Mountains; 9) geochemistry and mineral potential of granitic rocks in Arizona; 10) map showing geologic hazards in Arizona, 1:1,000,000 scale; 11) bibliography of geologic hazards in Arizona; 12) final report on potential geothermal resources in Arizona; 13) teachers resource guide for environmental education manual; 14) runoff processes in southeastern Arizona; and 15) geology and hydrology of the Basin and Range province in Arizona (a series of rock type, tectonic, mineral resource, and hydrologic maps and report).

A number of the projects listed above were done under contract with federal agencies, including the U.S. Geological Survey, Department of Energy, Nuclear Regulatory Commission and Bureau of Land Management.

Fieldnotes

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