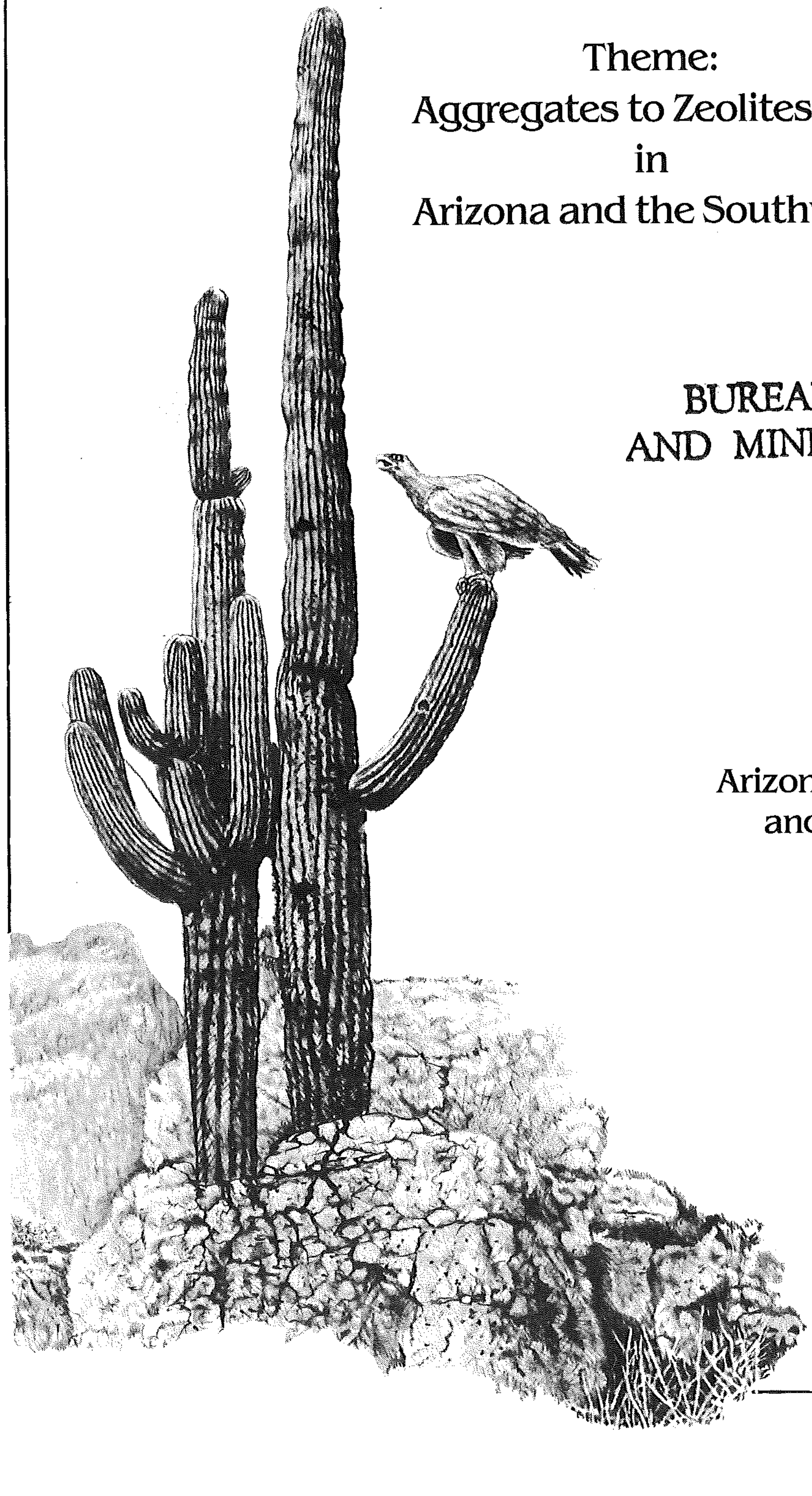
Proceedings of the

21st Forum on the Geology of Industrial Minerals



Theme:
Aggregates to Zeolites (AZ)
in
Arizona and the Southwest

BUREAU OF GEOLOGY
AND MINERAL TECHNOLOGY

edited by
H. Wesley Peirce

Arizona Bureau of Geology
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Special Paper 4
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Foreword

The 21st "coming-of age" meeting of the Forum on the Geology of Industrial Minerals was held April 9 through 12, 1985 in Tucson, Arizona, under the sponsorship of the Geological Survey Branch of the Bureau. Participants in this meeting, an official event of the University of Arizona's centennial celebration, came from 28 states, Canada, and Mexico. Seventy-five percent of the attendees were non-Arizonans.

The Forum was invited to Tucson to showcase the role of non-metallic minerals in the economic development of the sunbelt region of Arizona and the Southwest. Twenty-three reports were given and 22 of these are represented in these Proceedings, 16 as papers and 6 as abstracts only. All writing's were edited for general clarity and captions and bibliographies were standardized.

Special thanks are extended to the Society of Economic Geologist's Foundation, Inc., for a $500 grant to assist in publishing the Proceedings; Union Carbide, National Gypsum, Duval Corporation, Sil-Flô Inc., GSA Resources Inc., and D.W. Jaquays Co., for assistance with field trips; to Olga Hernandez for a heroic word processing effort, Jon Shenk for manuscript trouble shooting, Peter Corrao for cover graphics, to Joe LaVoie for publication assembly, and, of course, to all authors.

H. Wesley Peirce
General Chairman

Contents

Papers

Abstracts

Page

Mining and the Environment: Finding Common Ground

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ABSTRACT

For decades many of us who are associated with the mineral industry have tried to show the public its economic and strategic importance. Some of the mineral industry's proponents have been politically powerful figures and have been widely quoted. Yet, as measured by public opinion, legislative support, or almost any other standard, our efforts have been inadequate.

It is apparent that a set of environmental beliefs that discredit industry, firmly held by a number of idealistic persons, has had wider coverage in the media and in schools than has the mineral industry's message. Although the fervor of our idealistic friends is often unfounded and, their stands unscientific, they must be considered seriously. Unless we address the issues in terms the idealists will understand, the mineral industry will have little influence on them or on the general public.

A striking thing is that, quite often, translation of idealists' views into action has been counterproductive. The reason is obvious. Excessive amounts of money and energy have been spent on relatively minor problems. The common result is that larger problems have been created.

It may be possible to help anti-industry idealists understand their own dependence on minerals, and thus render their views more realistic, if they are shown more effective ways to reach their stated goals. If those goals can be shown to be held in common by all sensitive human beings -- including those in business and industry — the dialogue becomes one of how to achieve common ends.

Individual mining companies acting by themselves have little possibility of success, and companies working in unison through trade associations have not been successful. Further, it is unlikely that industry in general can be successful in changing minds unless it seeks outside help. But friends among those who influence public opinion have been hard to find. Historically, help from media has proven difficult to get. Nor has enough help from educators been forthcoming.

Yet, a war is going on in the technological, philosophical, and political trenches, even though much of the public is not aware of it. For the first time in years, there is now a significant and growing number of eloquent and brilliant thinkers on the side of free enterprise and industry, many of them environmentalists, but without the anti-industry mind-set. They have had remarkably little help from the private sector or even from the present administration. Industry may do far more for itself in the long run by encouraging these brave but bruised individuals and their organizations than by trying to work alone. These friends of free enterprise are working against a seemingly stacked deck relative to much of the media, the bureaucracy, and the educational system. However, despite their problems, their success to date has been remarkable. With more cooperation from industry they should do even better.

COMMENTARY

Early this January I was taking a limousine to Washington, D.C.'s National Airport and found myself alone with a well dressed, dignified gentlemen of about 70 who got on from one of the better Washington hotels. It turned out that he was from Phoenix and that he was very much concerned with a series of things. He was worried about the inequalities of wealth between the rich and poor people in the U.S. and between rich and poor nations. He felt that corporations, particularly some multinational corporations, should pay more taxes. He also expressed concern about uncontrolled industrial pollution and its effects on human health. As you might suspect, our conversation was lively.

Based on that short conversation, I think that I can guess much about why he was in Washington, what he may have done for a living, and what else he may believe. And, most important to us, what impact he and others like him have on the mineral industry and on industry in general.

First, I suspect he was in Washington lobbying for an environmental or social cause, possibly representing a group in Arizona, his home state.

Second, I suspect that a career in education and government allowed him to develop his particular anti-industrial brand of idealism.

Third, I suspect that he subscribes to a special set of environmental beliefs. For instance, he may believe: (1) that industry causes most cancer, (2) that industry is spewing wastes into the air and water and will ultimately poison us all, (3) that our nation is beset with problems caused by technology and the profit motive, (4) that we are destroying our forests, wildlife, fish, and soils, (5) that we are depleting our own and the world's energy and mineral resources, especially those of the poor countries, (6) that almost any sort of development is bad, especially mines, and (7) that mining is bad for the environment, and probably it is not really necessary, especially in our so-called post-industrial era. I could go on but you get the picture.

I suggest that my friend in the limousine has one other important belief. I think that he considers himself to be a good, patriotic American and is trying to do his best for our country and the world.

Finally, he and others like him are responsible for many of the problems which beset the mineral industry and, of course, industry in general.

Do we have any basis for believing that we can change the minds of this man or his friends? Can we say anything that he will hear? Keep in mind that if you actually can reach him, you might just find that opening up a new mineral deposit could be easier or that exploration in wilderness areas might just become possible, or you could find that some of the more oppressive and unrealistic regulations will diminish.

But reaching him has not proven easy. We in the mineral industry have tried education, with such influential people as former Secretary of State Alexander Haig talking eloquently about the resource war and the strategic implications of not developing our minerals. The American Institute of Professional Geologists' "Metals, Minerals and Mining" (1981) was an attempt to educate the public. People like Don Fife (1982) from California showed that being cut off from access to our mineral resources will cost future generations of Americans trillions of dollars. The Northwest Mining Association at their December, 1984, meeting devoted a full session to the so-called wilderness problem. Through the years there have been many such sessions. We have talked often about the cost in jobs, Arizona being a particularly good example. And we have talked of the folly of laws and regulations which seem at times to be only for the purpose of destroying an industry that provides vital commodities to society.

But how successful has all of this effort been?

First, even under the current administration you find still more areas being given wilderness designation which excludes even mineral exploration. In addition, according to the January 1982 issue of Engineering & Mining Journal, "Only 30% of all Americans view mining as necessary to the national economy, the national defense, or to the quality of life." In a survey conducted by Opinion Research Corporation only 16% of the Americans sampled felt familiar with mining. In an opinion section, 62% said that mining was dangerous and unhealthy, and 43% believed that it damaged the environment. Only one in seven persons viewed mining as helping industry to improve the energy situation.

The bottom line is on the December 17, 1984, Business Week cover. It reads: "The Death of Mining." Of course, environmental and regulatory pressures are not the whole problem, but they make a significant contribution.

Has it occurred to you that we may be doing something wrong? It certainly has occurred to me that I have. For one thing, I suspect that the people we have tried to reach may not even have been aware that we were talking to them, and even if they were, the words certainly had no measurable influence. Further, I see now that the words from the many of us who have spoken up have been largely directed toward reducing the impacts of symptoms. Unfortunately, there is almost an infinite number of sy0mptoms that can result from our common disease. I will suggest today that we should consider the disease, not the symptoms.

One problem that we may have failed to consider sufficiently is: can we realistically expect to educate people like my limousine friend only about our particular narrow interests? Perhaps our attempts at education should be broader than this and be put in their terms and framed in their scale of values. I think doing otherwise has resulted in failure in the past and assures failure in the future.

I would like to suggest today that there is a sound rationale for counteracting extreme environmental beliefs and I suggest that my friend in the limousine may understand and appreciate that rationale. I will also suggest how you may start a dialogue with him. And I will point out what you already know: it won't be easy. But I also suggest that you are now on the front of a favorable wave and with a little help from your friends, you may benefit enormously from it; most important, in my view, America can benefit enormously from it.

First, to understand the man in the limousine. Clearly, he is idealistic and his idealism leads him to expect perfection, almost as though he is somehow owed perfection, a society, an environment, an economy, a political system with no blemishes.

Basically, of course, the idealists -- those with unrealistic expectations -- are concentrated among those who do not work at creating wealth. Examples are the young and inexperienced, and those older persons with careers in academia and government. In addition, because it is easier to be idealistic if you do not have to worry about money, such idealists tend to concentrate among the well-educated middle and upper classes, the long-time wealthy. The wish of many of the idealists for a better world makes them vulnerable to those who know how to exploit their high motivations. The mind-set of the idealists is explained in a quote in California Mining (1984) from the famous motivational psychologist Abraham Maslow: "In a word, we tend to take for granted the blessings we already have, especially if we don't have to struggle or work for them. The food, the security, the love, the admiration, the freedom that have always been there, that never have been lacking or yearned for tend not only to be unnoticed but also even to be devalued or mocked or destroyed..."

Because the idealists tend to be well off, they are also well-educated. One may wonder, if they are so well educated, how come they are so unrealistic? Should not education lead to enlightenment? The California Mining article gives some clues. Quoting work by Inglehart (1977) they conclude that many people are"....buffered from and unaware of, the problems of goods production and natural resources except in the most theoretical way. As (they) become better educated, (their) goals and problems." Herman Kahn has called this "educated incapacity" and pointed out that it has led to the paradox that the more expert, or at least more educated a person, the more likely he is to be affected by "educated incapacity". I suggest that the blue-collared class has always known this.

All of this, of course, is well known to the Soviets. Hede Massing, who broke with the Communist party in 1981, said in an interview in Canada: "An idealistic approach works best among the privileged of America. It would be almost impossible to recruit the working class lectual and middle class. Communism appeals to the elite...." (Stevenson, 1984, p. 192).

Most, but obviously not all, of the idealistic environmental extremists who exhibit the anti-industry syndrome are patriots who are honestly trying to do what they believe is best. These are the people you may be able to reach because, as fellow-Americans, we want similar things: a better environment, less cancer and better health, less poverty, etc, with common goals we now have a basis for a dialogue about how best to achieve our common goals.

Let us now examine some of the idealists' efforts to solve these problems we have in common, because that is where they really need help. In each of the following cases I will suggest that by concentrating efforts on solving only a relatively minor component of a problem, or by expecting perfection, a much larger problem has been or will likely be created, i.e., in each case the problem-solving effort has been counterproductive in its own stated or implied terms.

First, cancer. The ideal is no cancer. Absolutely no one is against wiping out cancer. A logical step -- at least in many people's minds -- has been the total elimination of all cancer-causing agents. The battle cry has been "one fiber of asbestos can kill you" or "one molecule of a carcinogen can kill you". This is probably true. In a recent letter to Science, Norman Gravitz of the Edpidemiological Study Section, California Department of Health Services, agreed that the "one molecule can kill you" concept is, strictly speaking, correct (Gravitz, 1984). From epidemiological data he calculated, as an example, that one molecule of benzene consumed in a liter of water per day over a lifetime carries with it a probability of 10^{-22} that you will get cancer from it. Because the world population is 5×10^{9} the odds of any person living in the world today getting cancer from such exposure are 5×10^{-13} or one chance in 50 trillion. We would have to measure time in units of the geologic time scale before anyone got cancer from such exposure. Saying that one fiber of asbestos or one molecule of a carcinogen can kill you is like saying that crossing a street once or a single falling meteorite can kill you. These statements are true, but they are misleading if solemnly stated by so-called authorities.

Now, what happens when you apply modern technology to the "one-molecule-can-kill-you" concept? We find that we can now detect smaller and smaller amounts of many carcinogens and consequently we have a very expensive industrial nightmare, the problem of the shifting zero. As the limits of detectability drop, the acceptable limits for various contaminants also drop. As our ability to detect less and less improves, standards constantly shift downward as demanded by the idealistic concept of perfection -- the "one-molecule-can-kill-you" approach. How far downward? There is no real limit because virtually all contaminants with measurable vapor pressure contaminate everything and always have. Probably we are all daily taking into our system most poisons or carcinogens produced by man and nature. According to Dr. Raymond P. Mariella, former Dean and Vice President of the Loyola Medical Center: "If you look long and hard with currently available techniques, you probably will find vanishingly small concentrations of potentially toxic ingredients everywhere in everything."

Our regulators have attempted to reduce the risk of cancer from industrial products to zero -- the ideal or perfect situation. Vast sums of money have been spent to find industrial causes of cancer. In fact, the Toxic Substances Control Act mandates that this be the case. Not surprisingly, many are found because that is the expressed major purpose of so much government-sponsored research. Yet less than 5% of all cancer is caused by industry's chemicals (Higginson, 1980, p. 187). By concentrating on the less than 5% we have done proportionately less to understand and minimize the problems with the 95% attributed to all other causes. For example, we are now apparently finding that certain substances in food, such as carotene and Vitamin C, are apparently anticancer agents. We also know that each culture has its own special types of cancer but may be seemingly immune to others. What might we have learned had we devoted more funds to understanding such things?

Thus, excessive zeal applied to less than 5% of the causes of cancer may itself be an indirect cause of cancer because it must have reduced the money spent on research on the other 95% of all causes. As Weinberg (1984) said "....our preoccupation with small effluents of carcinogens from various industrial processes represents a serious misdirection of resources". Media distortions, at times aided by members of government, promote hysteria and displace real information about what can be done in everyday living to reduce the likelihood of contracting cancer. One has to wonder how many people have died because of a distorted perspective that leads to misdirected funding and energy, or misused media space and time? Trying to solve a relatively minor problem can, thus, create a larger one.

Having seen how efforts can be misdirected in handling a major health problem, let's look now at economics. Ideally there should be no poverty, no farm or business failures, or no economic inequities. Yet is this ideal at all realistic? As an extreme example, suppose a poor country tried to create this perfect situation. Instantly one realizes that no poor country can afford perfection, and to attempt to create and maintain this economic ideal would clearly bankrupt the country. We now suspect that even we, with our great wealth, cannot afford that economic ideal either. To try to attain economic perfection is to threaten national bankruptcy, a condition that would make us all poor. Applying the ideal of economic perfection can, therefore, create the problem it is trying to solve.

How about nature? If we define nature as perfection, then anything that we do to change nature is defined as creating imperfection, and more people result in more imperfection. This leads to the wilderness concept, leaving nature absolutely alone. This is a form of the one-molecule-can-kill-you concept applied to the natural environment.

I suggested at the Forum on the Geology of Industrial Minerals in 1983 that trying for the perfect environment at local levels could create much larger environmental problems for much larger areas. For example, I suggested that if we truly solved all of the micro-environmental problems associated with exploiting energy sources, we would not mine coal, drill for oil, or mine radioactive minerals. The result would be an environmental catastrophe. For instead of mineral fuels we would harvest and burn our forests just as all of the poor countries are now doing and just as we ourselves once did before we had our present alternative energy sources. Carbon dioxide in the atmosphere would be higher than necessary, erosion would increase, game would decrease, and recreational facilities would be lost. Thus the concept of saving the local environment from the effects of energy production would itself be environmentally destructive and would adversely influence the environment of entire regions. I called this problem "the dispersed-benefit riddle" although calling it the "dispersed problem riddle" may be better.

An example of the counterproductivity of expecting too much or going for the wrong goal has occurred at New York City. In the mid-1960's plans were drawn up for a new sewage plant for the west side of Manhattan so the Hudson estuary could be cleaned (Eisenbud, 1985). Environmental pressures led to insistence that the plant be redesigned to reduce by 90% the biochemical oxygen demand. Results: (1) after 15 years of construction, New York City has found that it has insufficient money for such a plant, and (2) insufficiently treated sewage continues to dump into waterways and there is little chance that it will change in the near future. Thus the idealistic expectation of more perfection than can be afforded has led to the problem's continuing.

The dispersed-benefit or dispersed-problem riddle is obviously far from solved because exaggerated and unrealistic environmental concern is potentially environmentally destructive; application of the "one-molecule-can-kill-you" concept to cancer research and regulations may cause neglect of broader research on prevention of cancer; attempting economic perfection can make us all poor; attempting too high a level of perfection in sewage treatment in New York City causes the problem to continue. These are a few examples of confused priorities and misdirected efforts resulting from an unrealistic environmentalism.

These examples are the essence of the dispersed benefit riddle or the other side of the coin, the dispersed problem. Trying to solve environmental problems by attempting to force conformity to unrealistic goals in practically all cases will increase the very problems we are trying to solve, will adversely influence more people or larger areas than if we had utilized our resources more wisely.

A different sort of example of confused priorities is clearly seen in the changes through the years in the nature of the work that my own company, Dunn Geoscience Corporation, does. My personal training was directed toward being a mineral explorer, a creator of wealth. Most all of DGC's staff have been trained to develop mineral or water resources. Originally, some 30 years ago when we began, almost all of our work was related to the production of wealth. Now, however, over 95% of our work is directed toward reducing the impacts of regulations, many of which are oppressive and unrealistic. As scientific entreprenuers, we responded to a changing world rather successfully. In fact, had we not done this we would now be either non-existent or very small. But what has really happened is that a group of people largely trained to create wealth or develop resources is now using too much of its talent to help people stay even or lose minimally. We, as a company, have benefitted; but the United States has lost. Our situation on a small scale is, I think, an accurate depiction of what has happened to much of our nation. Vast amounts of energy seem to have been misdirected.

Why are so many attempted solutions to social and environmental problems counterproductive in their own terms? In each case, concentrating on a small facet of a problem creates a larger problem. This appears to be a rule, applicable to many, many situations. We all know that if a company diverts its energy to nonproductive trivia it will soon go out of business. Keeping your eye on the ball is the game.

It is easy to see why so many of our environmental laws are questionable: they often are based on pop-science and hysteria. There is no way such laws could have been reasonable, could have really solved problems. They were based on apocalyptic pronouncements of the environmentalist of the 1970's. Recall that the influential environmentalist, Professor Paul Erhlich of Stanford University, once said in a scenario for the future that the oceans would be dead by 1979, that there would be massive world-wide starvation by 1985, that life expectancy for "Americans born since 1946 (when DDT usage began) would be 42 years by 1980" (Ehrlich, 1969). It is useful to know that oceans are still alive. It is useful to know that the world's per capita food production has increased about 1% per year since 1948 according to the UN's Food and Agriculture Organization (Osterfield, 1984). It is also useful to know that a book by the World Health Organization (1979) concludes: "No harmful effect has ever been reported in the vector control operators who have applied DDT during the past three decades in public health programmes" (p. 180), and "...the excellent safety record, never matched by any other insecticide used in antimalaria campaigns, other vector control programmes, and agriculture...." (p. 20). Further, DDT has saved millions of lives through malaria control.

Remember that Professor Barry Commoner, Director of the Center for the Biology of Natural Systems at Washington University at St. Louis, said that "In the process of creating new goods and services technology is destroying the country's capital of land, water and other resources as well as injuring people" (Efron, 1984, p. 36). It is useful to know that the most severe degradation of land, water and other resources and, the greatest problems with human longevity, were then, and have always been, in the low technology countries. Further, for the past 100 years mineral resources have only become more abundant as reflected by falling prices in terms of Consumer Price Index or relative to wages per hour (Osterfield, op.cit.).

And on September 11, 1978, Secretary of Health, Education and Welfare Joseph Califano said that industry is the overwhelming cause of cancer (Efron, 1984, p. 438). Yet, virtually all authorities on cancer in the world knew his figures were absurd at the time he stated them.

The counter arguments to most of the apocalyptic predictions have always been known to various experts in the relevant fields.

But it may be easy to forget that apocalyptic views were once so common, so fashionable and so accepted that when some of us tried to suggest that they may be wrong, our words were squelched because they were considered to be "too controversial". This is a curious phenomenon. Aleksandr Solzhenitsyn (1978), the Soviet author who defected, gives the reason in a 1978 speech at Harvard: "Without any censorship, fashionable trends of thought and ideas in the West are carefully separated from those which are not fashionable; nothing is forbidden, but what is not fashionable will hardly ever find its way into periodicals or books or be heard in the colleges". As Albert Einstein once said: "A fashion rules each age, without most people being able to see the tyrants that rule them".

Things are changing, fortunately. But do not feel too complacent. To my knowledge not a single one of the highest visibility environmental-thought leaders has ever been censured by the media, by his contemporaries, or in any other way. In fact, some seem to have only been rewarded. Professor Commoner, for instance, formed his own political party, The Citizen's Party, and ran for President in 1980; and Paul Ehrlich's work continues to be published since his astoundingly incorrect and gloomy predictions.

The apocalyptic thought leaders and the mind-set of the excessively idealistic among us are two factors that cause problems. A third is the media, which influences us all but, mostly, the idealistic. Often what we receive through the media is what has been called disinformation. It may have once been true, or appropriate, but the pressure of getting out news often means facts are not researched and updated. Surprisingly, every statement by our media may be correct, but on certain subjects it is easy to draw all wrong conclusions because only one side has been shown or obsolete examples have been used. Consequently, many of us find ourselves believing strange things like:

We are poisoning ourselves with industrial wastes -- even though we keep living longer;

Atomic energy is environmentally bad -- even though it is the cleanest, least polluting system we have;

We are amid a cancer epidemic -- even though several types of cancer are decreasing and cures are ever more effective;

Industry is destroying the environment -- even though industry and the wealth it creates are absolutely the only hope for long term environmental improvement;

We are running out of resources, even though the history of civilization is that resources expand as we learn better how to find and use them. Remember that at one time our major mineral resource was probably flint for arrowheads. And the ancient Athenians were concerned with their resource base when their per-capita income was "eight or ten dollars per annum" (Gramm, 1978) and their use of resources was a small fraction of those currently used.

The whole problem of counteracting illogical beliefs is compounded by groups that benefit from or are able to take advantage of the problems created by the inadequate public information system. This includes many politicians, lawyers, government bureaucrats, consulting firms and even some industries. As an example of the latter, those industries advertising products as being "all natural" are exploiting and reinforcing the position that manmade chemicals are, seemingly by definition, hazardous and, therefore, must be regulated more and more. I liken companies like mine, which benefit from the hysteria often produced by inferior information, to being like undertakers: someone has to do the work, but that does not necessarily mean that we favor killing people.

As mining people, can we improve the system? Can we help the good citizens among the environmentalists to achieve their stated goals? Obviously, changes are needed and priorities need reordering. The problem is very difficult because many things need to change, social attitudes first then some laws and regulations. If you concentrate your energy on problems created by the political left, you find yourself offending many wealthy people who either cynically gain from the confusion or have idealistically swallowed much of the contemporary environmental mind set; if you try to change the attitudes of the privileged who believe silly things, you may find yourself offending many of the clergy; if you try to show the folly of their positions on cancer, environment, etc., you find yourself seemingly being against motherhood-type causes. If you try to work through your trade associations, you may find that those associations have long ago been systematically discredited. Further, they are not usually oriented to deal with conditions in the technologic, economic and philosophic trenches -- and that is where the battles are.

Yet we must try to establish contact with so-called environmentalists and in terms they might understand. Clearly, education is the answer. Stevenson (1984, p. 246), talking about how the Nazis controlled information, said: "But the only safe counterweapon was freedom of ideas, freedom of expression, and a belief in the good sense of an informed citizenry." The lead article by K. W. Mote in the Northwest Mining Association's November, 1984, Bulletin is titled "Education is the Key to the Future of Mining". It is difficult to disagree with Mr. Stevenson or Mr. Mote about the importance of education.

Logically, then, we should work through the education system. Unfortunately, the record of our education system has not always been reassuring either. Most of us, I assume, have heard strange and incorrect ideas brought home from school by our children. London (1984), writing in Why are They Lying To Our Children?, tells us why in his review of some 70 textbooks used in our schools. He cites case after case where textbooks present the cluster of perspectives that I suggested my friend in the limousine might have. London concludes that in school texts wealth is assumed to be a given and "not treated as a precarious endowment that can be affected by bad judgment or reduced through trade-offs for other values". And he says further: "The texts exploit and bring to the surface the subterranean fears of the populous. There are either explicitly apocalyptic visions of rich nations fighting poor ones in a war of survival or suggestions that environmental hazards may well doom us all". In their one-sided view, the industrial nations, and particularly the United States, are cast as heavies, exploiting the poor. Clearly, we are creating some of our problems through our education system and our education system is contributing to what has been called "educated incapacity".

Another alternative is working through the media. To some extent we can and certainly must. But when we consider that the major national media have repeated with remarkable credulity and innocence (or, worse, without innocence) the wildest charges, it is difficult to feel reassured that they will really be helpful. Historically they have been part of the problem and not an answer. As Philip Abelson (1984) says in an editorial in Science: "The media are seemingly uncritical in their treatment of so-called deadly chemicals. In recent scares about dioxin they have roused sufficient public anxiety to force the agency (EPA) to give a minor matter top attention at the expense of more important risks to the public ". This is another example of the dispersed-problem riddle.

I do not suggest that we give up on the education system or the media. I suggest that we might get to them via another route I will now discuss.

So what can we do? Mainly, we can do what industry and business have probably failed to do to date: that is, support our friends, the friends of free enterprise. These are people who see very clearly the problems that I have described and their origins, and as individuals and as organizations, have taken on the thankless task of counteracting those problems. Thanks to these brave people it is becoming more and more difficult for our media to quote people who say things that are outrageously at odds with common sense or with scientific, statistical or economic data.

Some change in public perspective has already occurred naturally, because the public has undergone a national opinion pendulum swing. It has become skeptical of the carcinogen-of-the-month, the apocalyptic prediction-of-the-week, and so on. Most people, fortunately, have good sense.

But much of the change has occurred because of brave people like Edith Efron and her Apocalyptics; Simon and Kahn and their Resourceful Earth; Herbert J. London and his Why are They Lying To Our Children?; Wattenberg and his The Good News is The Bad News Is Wrong; Margaret Maxey's Regulatory Reform, and so many others; so many good ones, in fact, that it is difficult to have to leave out any of them. These people are first rate intellectuals and they have been attacked by the forces that seem to insist that we believe absurdities. What keeps our friends going, what helps them to feel less isolated, is reinforcement from others who have also put their reputations on the line to counter a disturbing trend. As their numbers grow and, if you will, as dispassionate logic backed by verifiable facts once again becomes fashionable among intellectuals, they will influence positively the future of the United States and the world.

Industry has given these people and their associations relatively little help. In fact, many people in industry have apparently felt that they could buy off their domestic detractors. Industrially financed foundations have contributed to industry's potential enemies 26 times more money than to their friends (L. Cordia, Heritage Foundation). The belief that industry can buy off its enemies is no more valid than the concept that we can buy off our national foes by disarming. Our enemies are implacable, and they see our contributions to them as weakness in us and as vindication that they are correct.

To repeat, help your friends. They have taken the time to get the facts that counterbalance the absurdities with which we have been bombarded. They have both credibility and intellectual credentials, so academics and idealists are much more likely to hear them. And they get quoted evermore by people in the media. They can tell the concerned but misinformed that we absolutely must encourage America's wealth-creating industrial machine, because without it no viable environmental, social or economic programs are possible. They can tell the people of our country that the mineral industry must flourish for the economic, strategic and environmental benefit of the nation. And they can most effectively question the whole mass of regulations and laws that were developed in an atmosphere of near mass panic. They can show how so many regulations and other government activities are counterproductive to solving problems of health, economics, environment, and social inequities that are the concerns of all good citizens.

Our free-enterprise friends and philosophers may ultimately have enough influence on the writers of textbooks, on legislators and on the idealists in general so that we as a nation will benefit enormously. They are the best hope for making sensible progress toward achieving the stated goals of the idealists for both the future of the mineral industry and the United States in general. They are the best hope because they are addressing the general problems, not just the problems of the mineral industry. They are finding a common ground.

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Geologic Setting of Industrial Rocks and Minerals in Arizona

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ABSTRACT

Arizona's geologic history is complex, resulting in a diversity of rock types and earth materials, including those of commercial interest. Regional variations in geologic history gave rise to three geologic provinces and an inequitable distribution of both metallic and nonmetallic mineral wealth. The Colorado Plateau is largely composed of flat-lying Paleozoic and Mesozoic sedimentary rocks and late Cenozoic volcanic fields and sedimentary deposits. Associated resources include gypsum, halite, sylvite, clays, specialty sand, flagstone, volcanic products, and aggregate. The adjacent Transition Zone features a large expanse of Proterozoic rocks, economically important Devonian and Mississippian carbonate rocks, and Tertiary volcanic and sedimentary materials. Nonmetallic resources in this province include facing and dimension stone, aggregate, decomposed granite, chrysotile asbestos, gypsum, clay, barite, fluorspar, zeolites, and limestone used for lime, cement, and railroad ballast. The Basin and Range Province has the most complex geologic history and, therefore, the most diverse assemblage of industrial mineral occurrences. These include halite, gypsum, clay, aggregate, decomposed granite, diatomite, zeolites, perlite, pumice, kyanite, limestone, marble, stone, and others. In addition, young stream deposits yield vast quantities of sand and gravel, Arizona's most economically important nonmetallic mineral commodity.

INTRODUCTION

The geologic history of Arizona is both complex and regionally variable. This is reflected by a diverse assemblage of rock types, structures, and mineral deposits, and by an unequal distribution of industrial rocks and minerals (Peirce - this volume). This paper summarizes the geologic evolution of Arizona, highlighting the geologic context of industrial rocks and minerals.

GEOLOGIC PROVINCES OF ARIZONA

Arizona consists of three geologic provinces — the Colorado Plateau (CP), Transition Zone (TZ), and Basin and Range Province (BRP) (Figures 1 and 2; Peirce, 1985). The CP of northeastern Arizona is geologically the simplest, largely because it escaped severe Mesozoic and Cenozoic tectonism. At the surface, it is largely composed of Paleozoic and Mesozoic sedimentary rocks that regionally dip gently to the northeast (Peirce, 1986). The underlying Proterozoic crystalline basement is exposed only in the bottom of Grand Canyon and in the Defiance Uplift, but has been penetrated in numerous drill holes (Peirce and Scurlock, 1972). Erupted over the Paleozoic and Mesozoic rocks are Neogene volcanic rocks, consisting largely of basalt with less abundant silicic to intermediate flows and tuffs. Cenozoic sedimentary deposits are also locally present, especially within present valleys and along the southern edge of the province. The structure of the CP is dominated by a regional northeast dip (due in part to pre-Late Cretaceous tectonism), Late Cretaceous to early Tertiary folds, especially monoclines, and Neogene normal faults.

In the adjacent TZ, uplift and erosional truncation of the northeast-dipping Paleozoic section has resulted in widespread exposure of the underlying Proterozoic crystalline rocks. Much of this erosional unroofing occurred in Cretaceous and early Tertiary time, based on the presence of detritus shed northeastward onto the CP (Peirce, 1986). The unroofed Proterozoic rocks were locally covered by Neogene volcanic and sedimentary rocks. An episode of mostly middle Miocene to Pliocene block faulting and basin filling was followed by erosional dissection of the basin fill during Pliocene and younger drainage integration.

The BRP is the most geologically complex region in Arizona. The geologic evolution of the BRP was comparable to that of the other two provinces during Proterozoic and Paleozoic time, but diverged by early Mesozoic time when the region became incorporated into the Cordilleran orogen. Multiple episodes of Mesozoic to early Cenozoic plutonism, metamorphism, and regional deformation, including thrusting, occurred during eastward subduction of various Pacific plates beneath southwestern North America. A middle Tertiary episode of crustal extension, accommodated by regional low-angle normal (detachment) faulting, was followed by high-angle normal faulting that

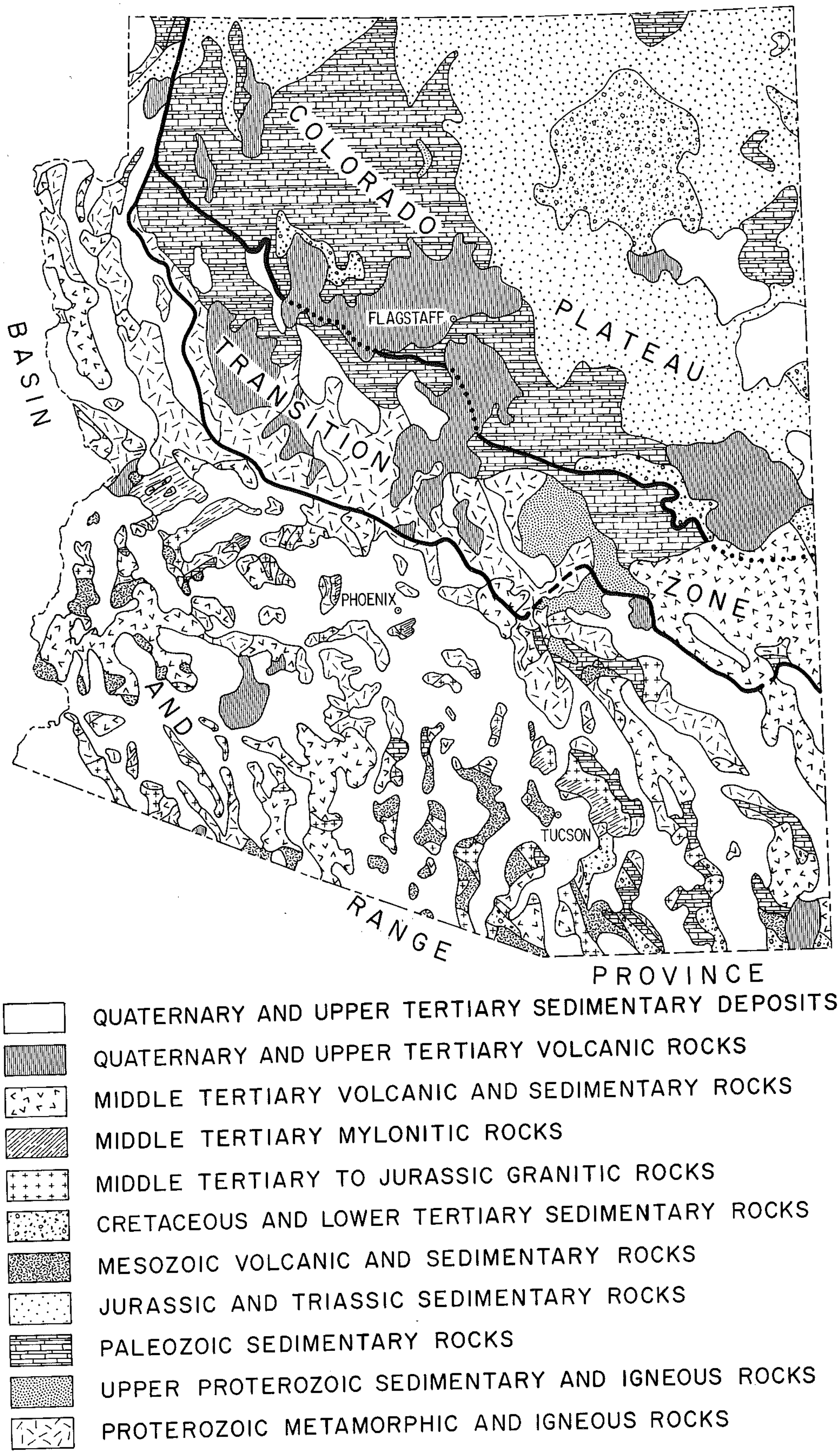

Figure 1. *Generalized geologic map of Arizona.*

<table>
<tr><th colspan="3" rowspan="2">GEOLOGIC TIME</th><th colspan="6">ARIZONA PROVINCES</th></tr>
<tr><th colspan="3">Basin & Range</th><th>Transition</th><th colspan="2">Colorado Plateau</th></tr>
<tr><td colspan="3">Quaternary</td><td colspan="3">Sand and Gravel</td><td>Sand and Gravel</td><td></td><td rowspan="3">Volcanics: Pumice; Cinder; Rock; S&G</td></tr>
<tr><td rowspan="5">TERTIARY</td><td colspan="2">Pliocene</td><td colspan="2">Peridot</td><td rowspan="2">Gypsum Zeolite</td><td rowspan="2">Clay (vitrified pipe)
Zeolite
Gypsum
Rock</td><td>Special clay
Special sand</td></tr>
<tr><td colspan="2">Miocene</td><td colspan="2">Halite; Perlite; Cinder; Pumice; Zeolite; Rock</td><td></td></tr>
<tr><td colspan="2">Oligocene</td><td colspan="3">Clay; Gravel</td><td>Gravel</td><td colspan="2"></td></tr>
<tr><td colspan="2">Eocene</td><td colspan="3"></td><td></td><td colspan="2">Gravel</td></tr>
<tr><td colspan="2">Paleocene</td><td colspan="3" rowspan="2">Formation of kyanite etc. and marble by mtamorphism</td><td rowspan="5">Not Present</td><td colspan="2"></td></tr>
<tr><td rowspan="4">MESOZOIC</td><td rowspan="2">Cretaceous</td><td>Up</td><td colspan="2">Clay (vitrified pipe)</td></tr>
<tr><td>Low</td><td colspan="2"></td><td>Lime</td><td colspan="2">Not recognized</td></tr>
<tr><td colspan="2">Jurassic</td><td colspan="3">Kyanite etc. protolith</td><td colspan="2">Sandstones</td></tr>
<tr><td colspan="2">Triassic</td><td colspan="3">Gypsum occurrences in western Arizona</td><td colspan="2">Rock; Gypsum; Petrified wood; Clay (bentonitic)</td></tr>
<tr><td rowspan="5">PALEOZOIC</td><td colspan="2">Permian</td><td colspan="2">Gypsum</td><td rowspan="4">Marble protolith</td><td>Gypsum</td><td colspan="2">Flagstone; Gypsum; Halite; Potash</td></tr>
<tr><td colspan="2">Pennsylvanian</td><td rowspan="3">Cement</td><td rowspan="2">Lime</td><td>Limestone and Shale</td><td colspan="2" rowspan="4">Not generally exposed</td></tr>
<tr><td colspan="2">Mississippian</td><td rowspan="2">Rock; Cement; Lime</td></tr>
<tr><td colspan="2">Devonian</td><td></td></tr>
<tr><td colspan="2">Cambrian</td><td colspan="3">Quartzite (flux); Locally Phosphatic (Abrigo)</td><td></td></tr>
<tr><td rowspan="2">P€</td><td colspan="2">Younger</td><td colspan="3">Quartzite (rock & flux)</td><td>Asbestos (chrysotile)
Quartzite (rock)</td><td colspan="2">Asbestos (chrysotile)</td></tr>
<tr><td colspan="2">Older</td><td colspan="3">Silica; Granite; Feldspar</td><td>Granite; Pegmatite; Stone (schist)</td><td colspan="2">Granite (rock)</td></tr>
</table>

Figure 2. *Time and geographic associations of selected industrial minerals in Arizona.*

helped block out many of the present-day basins and ranges.

PROTEROZOIC ROCKS AND THEIR USES

The oldest rocks in Arizona are Proterozoic volcanic and sedimentary rocks that were mostly deposited between 1.65 and 1.8 b.y. ago. These rocks, which formed in oceanic, island-arc, and continental-shelf settings, consisted largely of an older sequence of subaqueous mafic to felsic volcanic and volcaniclastic rocks with local pelitic units, and a younger sequence of subaerial rhyolite, quartzose clastic rocks, and thick marine graywackes (Anderson, 1986). Subsequent to deposition, both rock sequences were variably deformed and metamorphosed into schist, gneiss, mylonite, and other metamorphic lithologies.

The effects of deformation and metamorphism are extremely variable, both within small areas and between the three geologic provinces. This results in a wide variation in the physical properties, and therefore commercial uses, of Proterozoic rocks. Near Mayer in the TZ north of Phoenix, decorative facing stone is quarried from metarhyolite that was first hydrothermally altered and mineralized, and then metamorphosed into strongly foliated schist. Near New River, slaty to phyllitic Proterozoic rocks are mined for use in the manufacture of vitrified clay pipe (Morris - this volume).

Proterozoic rocks in the BRP in western Arizona represent a deeper exposed level of the Proterozoic crust and are generally compositionally banded high-grade gneisses not presently exploited for industrial uses. Less deep-seated Proterozoic rocks in southeastern Arizona are dominated by schistose metagraywacke that is likewise not extensively utilized. Industrial uses of foliated Proterozoic rocks, such as for facing stone, apparently require the spatial coincidence of a suitable protolith and a special history of metamorphism, deformation, and possibly hydrothermal alteration.

In addition to the metavolcanic and metasedimentary rocks, Arizona contains several generations of Proterozoic granitic rocks (Silver, 1978). The oldest generation consists of dioritic to granitic plutons emplaced before, during, and slightly after deformation and metamorphism at 1.65 to 1.75 b.y. ago. Plutons emplaced before or during deformation commonly have a variably developed foliation, mylonitic fabric, or metamorphic layering, characteristics that limit the strength of the rocks and their potential uses. A relatively undeformed 1.7-b.y.-old granite located near Payson in the TZ is used as road metal and fill. Plutons emplaced after deformation, such as a younger generation of undeformed 1.45-b.y.-old porphyritic granites, have been locally quarried for dimension stone and crushed for use as aggregate. A popular current use is in desert landscaping, as around the State Capitol in Phoenix. Screened fines from crushed Proterozoic granite are currently being tested for use in "clay" tennis courts.

In the CP, a Proterozoic granite crops out near the southern end of the Defiance Uplift where it is depositionally overlain by Permian strata. This very durable rock, representing part of the Paleozoic Defiance positive area (Peirce, 1976a), was recognized as a potentially important source of crushed rock (Kiersch, 1955, p. 33-35) and subsequently used extensively for road building.

The youngest Proterozoic rocks in Arizona are 1.1- to 1.2-b.y.-old sedimentary and volcanic rocks of the Apache Group and Troy Quartzite in east-central Arizona (TZ) and southeastern Arizona (BRP), and the Grand Canyon Supergroup in Grand Canyon (CP). Diabase sills and dikes widely intruded these rocks 1.1 b.y. ago, resulting in the formation of major deposits of chrysotile asbestos in the Mescal Limestone of the Apache Group (Wrucke and others, 1986) and to a lesser extent in the Bass Limestone of the Grand Canyon Supergroup. The Mescal Limestone was also used as dimension stone for construction of the 284-feet-high masonry Roosevelt Dam in the TZ. Resistant units in the Apache Group and Troy Quartzite are also locally crushed for aggregate. Additional commercial uses of rocks in the Apache Group are possible, since new scientific discoveries are still being made, such as the recognition of K-metasomatized tuffs in the sequence (Wrucke and others, 1986, p. 16).

PALEOZOIC ROCKS AND THEIR USES

During Paleozoic time, Arizona was part of the North American craton and received a generally thin (1 to 1.5 km thick) cover of carbonate and clastic rocks (Peirce, 1976a). The stable cratonic setting was interrupted in Pennsylvanian to Early Permian time when uplifts and basins formed during tectonism in the ancestral Rocky Mountains. Paleozoic carbonate rocks, especially those of Mississippian age, are utilized in two cement plants, one in the BRP near Tucson and another in the Verde Valley of the TZ. They are also a source of railroad ballast and lime (near Nelson) in the TZ and are used in the copper industry for lime and flux stone. Other resources in Paleozoic rocks include (1) potash and salt (sylvite and halite) in the Permian Holbrook Basin of the CP (Peirce and Gerrard, 1966); (2) gypsum in the Permian Kaibab Formation, the youngest Paleozoic unit on the CP; and (3) flagstone from the Permian Coconino Sandstone (CP). In addition, liquified petroleum gas is stored in underground solution cavities in evaporite zones in the upper part of Supai Formation, above the Fort Apache Member (Peirce, 1981; Peirce and Wilt, 1970, plate 15.).

The thermal history of Paleozoic rocks varied significantly from area to area (Wardlaw and Harris, 1984; Reynolds and others, in press). This is partly revealed by the color-alteration index (CAI) of conodonts, a phosphatic microfossil that systematically changes color when heated. CAI studies indicate that Paleozoic rocks in the CP and northeastern TZ were only raised to temperatures as high as 50 to 100 $^{\circ}$C during post-Paleozoic thermal events (Wardlaw and Harris, 1984). In contrast, Paleozoic rocks in the BRP widely reached temperatures of 250°C and higher. As a result, Paleozoic quartzose clastic rocks in the BRP tend to be quartzites. Carbonate rocks in the BRP are locally marbles, especially near large intrusions or where thrust-related deformation and metamorphism occurred. Quartzite is used for aggregate and smelter flux, whereas crushed marble is used for livestock feed additive, white pool sand, and various other applications.

TRIASSIC AND JURASSIC ROCKS AND THEIR USES

Triassic history of the BRP is poorly known because Triassic rocks are not widely preserved or recognized (Peirce, 1986; Stewart and others, 1986). Quartzose clastic rocks probably correlative with Triassic Moenkopi Formation have been recently recognized in west-central Arizona (Reynolds and others, 1987), and these rocks locally contain gypsiferous zones. By Early to Middle Jurassic time, much of the BRP evolved from a cratonic setting into part of the Cordilleran orogen (Coney, 1978; Dickinson, 1981). Jurassic rocks of the BRP include widespread silicic to intermediate ash-flow tuffs, flows, and volcaniclastic rocks, continental sedimentary rocks ranging from fine-grained red beds to coarse sedimentary breccia, and several generations of granitic plutons (Tosdal and others, 1987). Jurassic volcanism and magmatism was locally accompanied by intense hydrothermal alteration and metasomatism that extensively leached mobile elements from the affected rocks, leaving high concentrations of less mobile elements, such as Al, Ti, and P. Metamorphism either during or after metasomatism produced highly aluminous rocks composed of quartz, kyanite, andalusite, pyrophyllite, rutile, dumortierite, tourmaline, and other minerals (Reynolds and others, in press). These quartz-kyanite rocks were mined in adjacent southeastern California for use as a refractory material and may have further economic potential because half of the known occurrences in Arizona were discovered since 1980. Potentially commercial pyrophyllite deposits may also exist, based on the presence of over 100 m of pyrophyllite in exploratory drill holes in the central Dome Rock Mountains of western Arizona (J. Loghry, 1987, personal communication). The pyrophyllite occurs in altered Jurassic volcanic rocks and may be related to either Jurassic or Late Cretaceous magmatism and alteration.

In contrast to the BRP, the CP region remained tectonically stable, but received abundant detritus derived from an orogenic belt somewhere to the south and west (Peirce, 1986; Stewart and others, 1986). Triassic Moenkopi Formation, the oldest Triassic unit on the CP, has been used for dimension stone and contains interbedded gypsum in northwestern Arizona (CP). The overlying Upper Triassic Chinle Formation, which records the influx of volcanic ash and detritus from the south and west, has abundant ash-derived clays and semiprecious petrified wood; the basal Shinarump Conglomerate Member is used for aggregate. Overlying the Chinle Formation are Jurassic continental and marginal marine sedimentary rocks of the Glen Canyon Group, San Rafael Group, and Morrison Formation.

CRETACEOUS AND EARLY TERTIARY ROCKS AND THEIR USES

Beginning in the Late Jurassic and continuing into the Early Cretaceous, faulting in the BRP created basins in which thick sequences of mostly nonmarine clastic rocks accumulated (Dickinson, 1981). These sequences include the Bisbee Group in southeastern Arizona and the McCoy Mountains Formation in west-central Arizona. The Mural Limestone, a marine limestone in the Bisbee Group, is used in the production of lime near Douglas in southeasternmost Arizona.

A younger, unrelated sequence of Cretaceous rocks occurs on the CP and includes nonmarine and marine strata of the Dakota Sandstone, the Upper Cretaceous Mancos Shale, and the Mesa Verde Group. The latter rocks are mined for coal on Black Mesa and for kaolinitic shale near the Mogollon Rim in east-central Arizona (Morris - this volume).

In Cretaceous to early Tertiary time, southern and western Arizona was the site of widespread large-scale folding and thrust faulting (Drewes, 1981; Haxel and others, 1984; Reynolds and others, 1986a). Deformation was locally accompanied by metamorphism that converted Paleozoic and Mesozoic supracrustal rocks to schist, phyllite, marble, quartzite, and calc-silicate rocks (Reynolds and others, in press).

Late Cretaceous to early Tertiary (Laramide) tectonism was also accompanied by caldera collapse due to eruption of extensive ash-flow tuffs, by construction of andesitic stratovolcanos, and by emplacement of plutons ranging from subvolcanic porphyries to mid-crustal muscovite-bearing granites. Hydrothermal alteration and mineralization occurred near many porphyry intrusions (Titley, 1982), forming large porphyry copper deposits and local higher-level alunite and kaolinitic occurrences within wall rocks of the intrusions. Altered zones associated with a Late Cretaceous granite in the San Tan Mountains south of Phoenix are used for decorative landscaping material. During and subsequent to Laramide tectonism, much of the TZ and BRP was uplifted, resulting in shedding of detritus (Rim gravels) onto the CP and development of a widespread erosion surface beneath middle and upper Tertiary rocks.

MIDDLE TERTIARY ROCKS AND THEIR USES

After an Eocene volcanic quiescence, volcanism swept westward across the BRP, starting in southeastern Arizona at about 30 to 35 Ma and reaching western Arizona by 20 to 25 Ma (Coney and Reynolds, 1977; Shafiqullah and others, 1980; Reynolds and others, 1986b). Silicic ash-flow tuffs and flows are ubiquitous within middle Tertiary volcanic fields, along with locally abundant basaltic and andesitic rocks. Volcanism was accompanied at depth by the emplacement of granitic plutons and extensive dike swarms.

Middle Tertiary tectonism was dominated by major crustal extension, generally accommodated by large-scale transport on regional, gently dipping normal faults, called detachment faults (Davis and others, 1986; Spencer and Reynolds, 1987). Gently dipping mylonitic fabrics in the footwall of many detachment faults were formed by an earlier phase of deep-level ductile shear along the fault zones. Rocks above detachment zones are commonly cut by normal faults into numerous tilted fault blocks that are truncated downward by the detachment fault. Half-grabens between the crests of adjacent fault blocks locally received thick accumulations of clastic and volcanic rocks.

The main industrial mineral commodities in middle Tertiary rocks are (1) perlite associated with silicic flows; (2) clays used in the production of cement and brick, and in earthen-construction (adobe and rammed earth) homes; and (3) minor vein barite. Some middle Tertiary volcanic fields also contain pumice and "Apache Tears," semiprecious obsidian nodules that occur within perlite and devitrified rhyolite.

UPPER TERTIARY AND QUATERNARY ROCKS AND THEIR USES

Middle Tertiary extension along low-angle detachment zones was followed by the Basin and Range disturbance, a late Tertiary episode of high-angle normal faulting that outlined many of the present-day basin-and-range-type fault blocks (Eberly and Stanley, 1978; Scarborough and Peirce, 1978; Shafiqullah and others, 1980). Basins that formed over downdropped blocks were filled with detritus eroded from the flanking upthrown horst blocks. Coarse detritus deposited near the mountain fronts graded into finer grained clastic deposits toward the interior of the basins. Up to 3 km of nonmarine evaporite deposits, mostly halite and anhydrite, are interpreted to be present in certain late Tertiary basins (Peirce, 1974, 1976b, 1981). Salt (halite) in the Luke Basin near Phoenix is utilized for two purposes: (1) as a source of salt products produced by solution mining and solar evaporation; and (2) for storage of propane and butane in underground solution cavities. A similarly thick halite sequence in the Red Lake basin of northwestern Arizona will probably also be utilized someday.

Of the approximately 150 basins within the BRP and TZ of Arizona, few have been adequately explored by drilling. The potential for valuable chemical precipitates, such as chlorides, sulfates, and borates, though unknown, may be substantial. In addition, the deeper parts of many basins may contain saline brines, inasmuch as the salinity of groundwater commonly increases with depth (Peirce, 1969 ,1976b).

On the Colorado Plateau, the Basin and Range disturbance did not produce major basins, but did result in substantial late Tertiary to Quaternary offset on faults in northwestern Arizona. Changing tectonic or climatic conditions also caused the formation of Pliocene Lake Bidahochi along what is now the Little Colorado River Valley. Fluvial sands derived from the adjacent Defiance Uplift were deposited in the Bidahochi Formation and are properly sized and rounded to be used as hydrofrac sand in petroleum production. Below the sands are special clays that formed by alteration of air-fall tuffs and that have been mined since 1925 (Eyde and Eyde - this volume)

Sedimentary units (basin fill) deposited in late Tertiary basins and on buried pediments flanking the range fronts locally contain tuffaceous rocks that have been altered to zeolites (Jett, 1978). The Bowie chabazite deposit in southeastern Arizona, because of valuable commercial production, is the best known occurrence of these (Eyde, 1978; Sheppard and others, 1978, p. 319-328). Basin fill also hosts deposits of gypsum and diatomite in the BRP and occurrences of gypsum and zeolites in the TZ.

Another manifestation of late Cenozoic tectonism was volcanism in all three geologic provinces. Basaltic volcanism became widespread 15 m.y. ago (Shafiqullah and others, 1980; Reynolds and others, 1986b) and has locally continued into the Holocene. On the CP, basaltic cinders quarried from Quaternary cinder cones in the San Francisco and

Springerville volcanic fields are widely used (Welty and Spencer - this volume).

In the BRP, basaltic cinders were once mined in the San Bernardino Valley of extreme southeastern Arizona. Basaltic rocks are locally crushed for road material and are used in the fabrication of glass wool at Casa Grande. Basaltic boulders in talus aprons are harvested for rip-rap, such in the Palo Verde Hills west of Phoenix. Also, gem-quality peridot is recovered from mantle inclusions in a basalt flow on Peridot Mesa in the San Carlos Indian Reservation.

Although basalt is by far the most abundant Upper Tertiary to Quaternary volcanic rock, dacitic to rhyolitic flows and tuffs occur in the San Francisco and White Mountains volcanic fields (CP). Pumice from the San Francisco volcanic field was blended with cement as a pozzolan during the construction of Glen Canyon Dam, and material suitable for light-weight aggregate is being transported to Phoenix.

As basin-and-range-style faulting decreased in intensity during the last 4 m.y., internally drained (closed) basins became integrated into the regional drainage network emptying into the newly opened Gulf of California. Sand and gravel deposited on pediments and along rivers and washes are the State's most important source of aggregate (Langland - this volume).

CONCLUSIONS

The complex geologic history of Arizona has resulted in a great diversity of known industrial rock and mineral deposits. Variations in geologic history between the State's three provinces are reflected in an unequal distribution of geologic materials and associated nonmetallic products. Much remains unknown about the geology of Arizona, especially in the Basin and Range Province -- major geologic discoveries are still being made and significant geologic problems remain unresolved. There is, therefore, much potential for future discoveries of industrial mineral deposits, both of deposit types already known and of new types not yet widely anticipated. It is fortunate that most of the State's population growth is in the geologically complex Basin and Range Province, where industrial minerals production, and future opportunities, are greatest.

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Industrial Minerals and Rocks of Arizona

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ABSTRACT

Arizona embraces portions of two major western-U.S. physiographic-geologic provinces and a smaller, local one. These exert fundamental control over the geologic framework and associated earth-material resources and potential. The Mogollon Rim diagonally crosses the State and separates the Colorado Plateau Province to the northeast from the Transition Zone and Basin and Range Province to the southwest. More than 90 percent of the population, production of nonfuel minerals, agricultural land, and water resources are in the Basin and Range part of the State.

In 1981 Arizona was ranked number one in the Nation with respect to the value ($2.56 billion) of nonfuel-mineral production. About 8.2 percent of this amount ($212.9 million) can be attributed to nonmetallic (industrial) materials. Although a diversity of nonmetallic substances is produced and some are exported, the bulk is utilized within the State and is directly related to market growth. Since 1950 there has been a fourfold increase in Arizona's population, a concomitant twelvefold jump in sand-gravel production (tons), and a twentyfold increase in "stone" production. New industries developed during this time include cement, salt (and storage of liquid petroleum gas products in solution cavities in salt), zeolite, hydrofrac sand, vitrified clay pipe, crushed marble products (feed additive, pool sand, roofing granules, etc.), and "rock" wool. Most of these newer industries serve out-of-State as well as in-State markets. In 1981 at least 225 industrial mineral or rock deposits were being worked to produce about 10 tons of material per Arizona resident per year. In 1980 the relative values of basic industrial minerals produced in the State, by major group, were cement and lime (51.6 percent); gravel (26.5 percent); sand (11.8 percent); stone (4.6 percent); and others (5.5 percent).

Detailed knowledge of the nonmetallic rock-and-mineral content of most Arizona ranges and basins is lacking. Exploration opportunities in this sun-belt growth region appear encouraging.

INTRODUCTION AND OVERVIEW

Industrial minerals and rocks are the staff of life, the bread and butter of the mineral world. They are those naturally-occurring, inorganic, nonmetallic-appearing rocks and minerals that enter into commerce. They include the more mundane, everyday rocks and minerals of the earth - the sands, gravels, limestones, clays, salts, cinders, etc., that usually do not figure in "get-rich-quick" schemes. Someone, however, has to discover and develop these natural materials if we are to have the conveniences (houses, roads, etc.) that are the hallmark of modern civilization. Most of us are users, not producers, and we know little about the blood, sweat, tears, knowledge, imagination, risk, patience and investment that lie behind the everyday things that we all use, but take for granted. Over the long haul it would appear unwise to lose sight of the basic supports of modern life, which include essential industrial minerals and rocks.

As is often emphasized, Arizona can be subdivided into three contrasting geologic-physiographic provinces or regions. These, along with some of their associated industrial minerals (IM), are shown in Figure 1.

As might be expected, Arizona's industrial minerals (IM) industry is strongly influenced by population, industrial growth, and the condition of the economy. We are the sixth largest state in area and have been near the top in population growth over the past decade. At the same time we are the sixth least populated state per square mile.

Figure 2 is an attempt to show the state's steady population gain for the period 1950-1982 as well as the fluctuating, though generally rising, production curve for common IM materials such as sand-gravel, and stone. The production fluctuations, in contrast to the steadily rising population curve, reflect changing economic conditions. The gross value curve, on the other hand, reflects the effects of price inflation, especially since about 1974. This demonstrates that true growth is better represented by production and not value trends. Since 1950 there has been a fourfold increase in Arizona's population, a concomitant twelvefold jump in sand-gravel production (short tons), and a twentyfold jump in "stone" production.

In 1981 Arizona was ranked number one in the nation with respect to the value ($2.56 billion) of nonfuel-mineral production (Burgin, 1983). About 91.8 percent of this

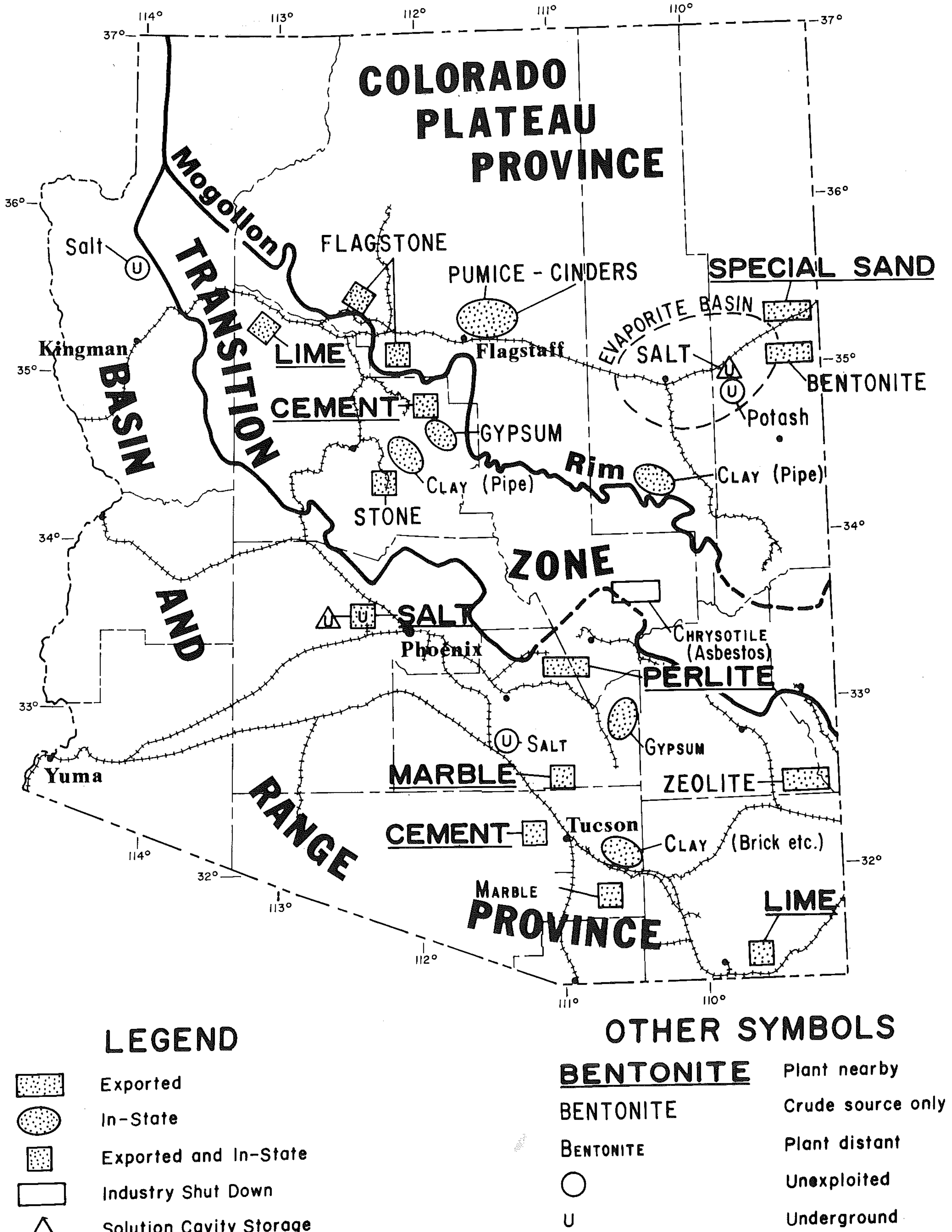

Figure 1. Map of Arizona showing geologic provinces, general locations of major industrial minerals operations, and some undeveloped deposits.

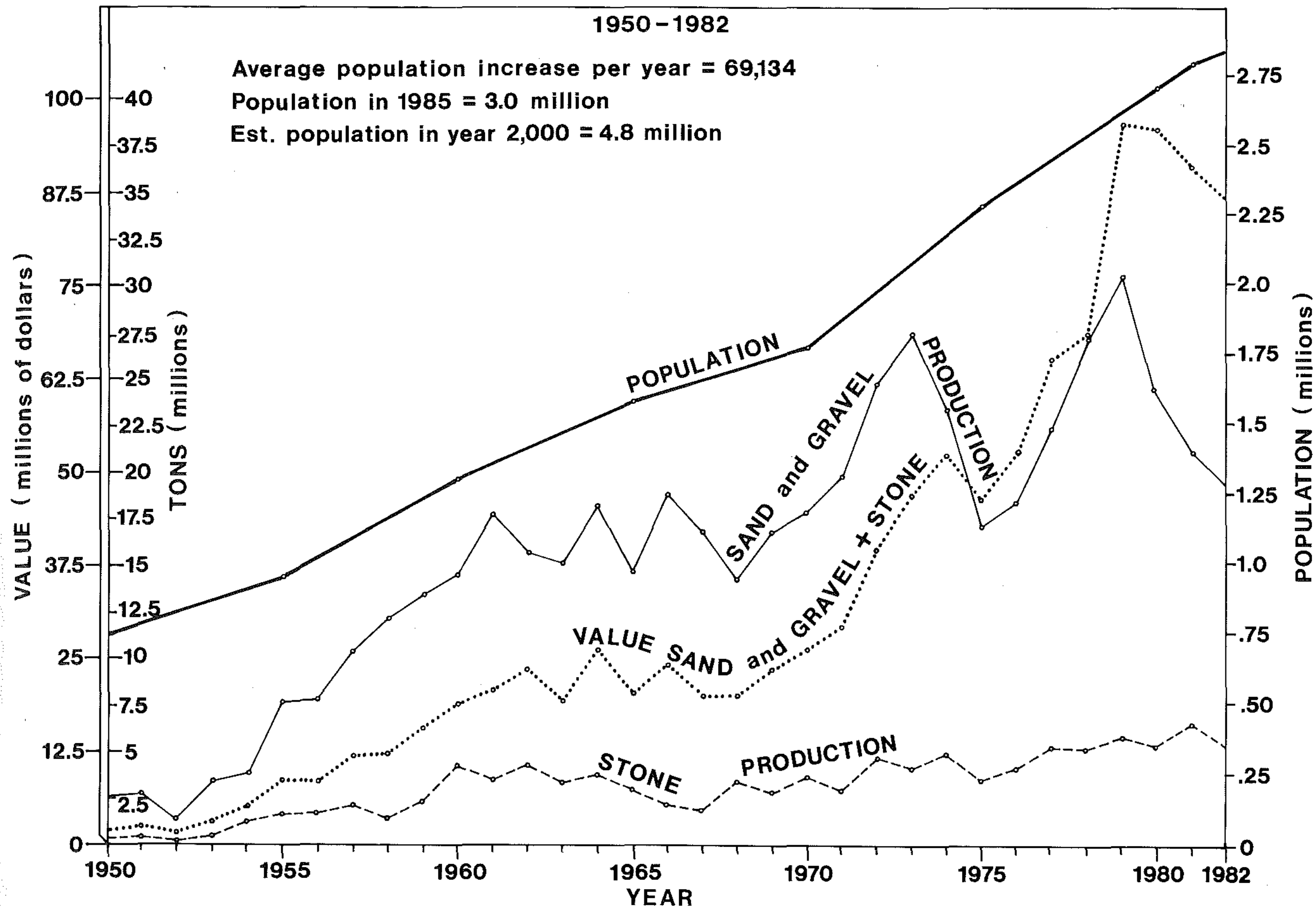

Figure 2. Graph showing growth in Arizona population, production (tons) of sand-gravel and stone, and combined value of these groups, by year, for the period 1950-1982.

value is attributed to metals, especially copper. The remaining 8.2 percent ($212.9 million) is credited to the nonmetallics. It should be pointed out, however, that dollar value is not always a valid measure of basic usefulness or need. It is axiomatic that the necessities of life tend to be low cost (air, water, food, construction materials, etc.).

Figure 3 is an attempt to illustrate both the production and value aspects of the major IM groups for the year 1980. As an example, combined sand and gravel made up over 81 percent of the weight and 38 percent of the value. On the other hand, the weight of combined cement and lime was about 6 percent of the total whereas this group made up over 51 percent of the value. Also shown are some miscellaneous statistics including a per-year production of over eleven tons of IM per Arizona resident. The value assigned to the total IM production for 1980 ($192.5 million) equates to about $71.3 per person, or, $6.42 per ton.

PRINCIPLES AND HIGHLIGHTS

General Statement

In Arizona, IM affairs have taken a backseat relative to the metals, especially copper. As a consequence, IM related activities tend to be carried on quietly and without fanfare. With this in mind the remainder of this paper will be devoted to some general principles and examples regarding the development of IM deposits in Arizona.

Raw Materials Supply and Planning

Supplying the raw-material needs for a large and growing community, such as Phoenix, is an ongoing, dynamic, everyday process that is completely understood by no one person. That there should be a diversity of opportunities, misunderstandings, and conflicts in carrying out this complex process seems inevitable. While most citizens accept the end-use

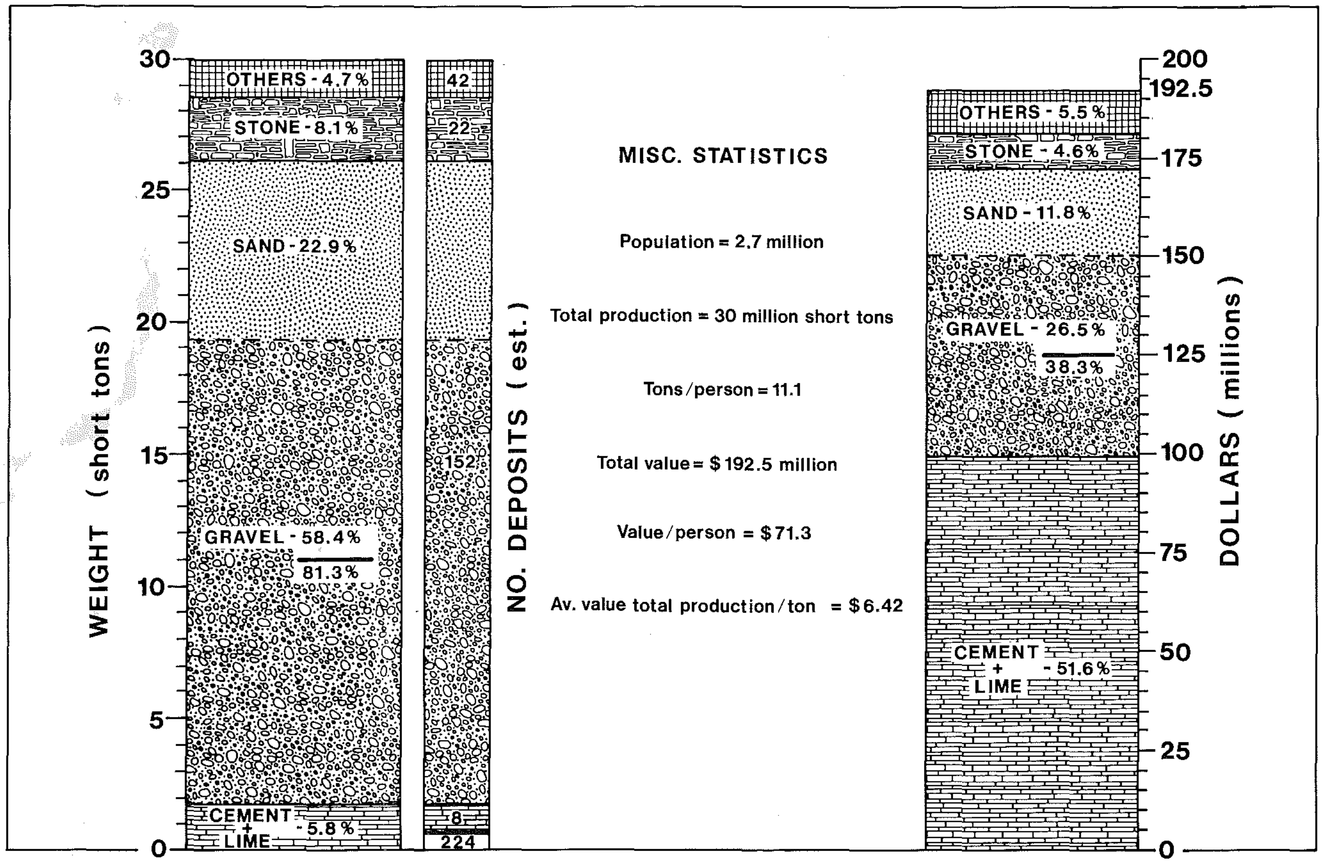

Figure 3. *Illustration showing production of Arizona nonmetals, by weight and value of major groups, for the year 1980, and miscellaneous information.*

benefits of mineral and energy resources development, they do not, quite naturally, want the in-between procedures to significantly intrude upon their daily lives. Having one's cake and eating it too seems an apropos description. It is, however, possible to have it this way as long as we are willing to (1) pay the price ($), and (2) allow the raw materials to be sought, found, and developed. The latter aspect, however, is becoming increasingly difficult. Much emphasis is being placed on community planning. Wise planning, it would seem, should include consideration of all important aspects of community life. One of the more difficult tasks is giving serious, long-range consideration to the ongoing nourishment that is essential to the maintenance and growth of a viable community through an uninterrupted flow of essential raw materials at a reasonable cost.

Discovery and Recognition

Most of the earth's crust consists of rocks and minerals that are nonmetallic in character. Whether any of these earth materials might be subject to eventual exploitation is a function of many variables. The more diverse the geologic character of a region the more likely will there be occurrences of useful materials capable of contributing to the fulfillment of local and/or more distant needs. Where geologic diversity pertains, as it does in Arizona, recognition (discovery) of the existence, nature, or utility of a naturally occuring substance may be substantially delayed (there is always more to learn). One reason for delayed recognition is burial. Even surface occurrences can, for technical reasons, escape detection, accurate characterization, and evaluation. There is, for instance, an evolutionary aspect to usefulness in that needs change or accrue in response to increasing technological variety and sophistication.

Subsurface discovery can be either accidental or a consequence of deliberate exploration for the substance sought. The discovery of the Luke Salt Body near Phoenix is an example of the latter. In this case a market survey had indicated that salt was being imported into Arizona in quantities that, if produced locally, could support an operation. A search began and, in 1968, a salt body was penetrated at 880 feet below a cotton field west of Phoenix near Luke Air Force Base.

This relatively new industry continues to expand and fluorish (Figure 1, See Grott - this volume).

An example of a surface occurrence, the characteristics of which went unrecognized until 1959, is the Bowie chabazite deposit in southeastern Arizona (Figure 1). Chabazite is a zeolite mineral that is processed to make a high-value, molecular sieve product. This deposit had its geological beginnings in a Mt. St. Helens-type ash fall that was subsequently altered to zeolite by chemical processes attendant to a saline-lake environment. The constituent minerals can be identified only in the laboratory by sophisticated X-ray and SEM techniques. Prior to the recognition of its specific mineral content, this material, because of its light weight and ease of shaping had been used as a local building stone. The true nature of this deposit was discovered as a result of an exploration effort to inventory and characterize natural occurrences of zeolite in the west. This interest in natural zeolites was stimulated by technological developments in the use of molecular sieves. Since 1962 the Bowie chabazite deposit has yielded the most mined tonnage of any natural zeolite deposit in the United States. About 12,000 tons of crude chabazite, valued at about $30 million in its processed form, has been produced. All production of crude is shipped out of state for final processing and use.

Relative Value and "Commonness"

IM constitute a group of earth materials having a wide range in value and use. Sand and gravel, usually considered to be "common", might sell for $3.00 per ton whereas less common zeolite, such as the Bowie chabazite, might be worth almost one thousand times as much in its processed form. The higher volume - lower cost materials tend to be used locally whereas the lower volume - higher cost products often are exported to serve a specialized market. Whereas the former tend to be sought after and developed as close to a center of consumption as possible, the search area for the latter is much less influenced by market location.

"Commonness" is relative. Sand and gravel, though common around the Phoenix region, could not satisfy the rigid specifications for concrete aggregate at the Palo Verde Nuclear generating plant. Gravel for concrete use was hauled from higher-quality (low volcanic content) deposits near the Colorado River to the west. Clay for brick making is usually considered to be common because brick is a common product. When used as a building stone, however, the Bowie zeolite was also "common". In terms of its present use, it is not. The most important contributor to brick-making in Arizona is the Pantano clay southeast of Tucson (Figure 1). This material, in addition to supplying Tucson, is trucked to Phoenix where it is blended with material from local deposits to make red brick. It is also a source of alumina in the manufacture of portland cement near Tucson. Although it could be said that these are common uses this clay-shale is uncommon in Arizona. It may prove to be suitable for selected, less common, ceramic uses. Time will tell.

Locations of Raw Materials and Processing Plants

Most nonmetallic minerals and rocks undergo some type of processing, somewhere. In certain cases the processing is done close to the deposit and in others the raw materials are delivered to plants either in or out of Arizona. One of the newer IM - based industries in the State is the manufacture of vitrified-clay pipe near Phoenix. Although the Phoenix market area is fundamental, pipe is also shipped into Nevada, Utah, New Mexico, and California. In this case, raw materials from three widely separated sources are trucked to the Phoenix-area plant (the two vitrified pipe clay sources are shown on Figure 1). Much effort and trial and error testing were given to the recognition, acquisition, and development of natural materials capable of making an acceptable raw-materials mix (Morris - this volume).

In 1980 over half of the value of industrial mineral and rock products produced in Arizona is attributed to combined cement and lime ($100 million). There are two cement plants and two lime plants making commercial products (Figure 1). In this case, in contrast to the vitrified-clay pipe plant, each plant is located near large reserves of the principal raw materials requirement, limestone. Because no suitable limestone deposits occur in the Phoenix region (Maricopa County), the products derived therefrom must be transported from outlying regions if there is to be continued maintenance and growth.

Conflicts

Inevitably, in the attempt to supply raw-material requirements, there are impacts associated with production, processing, and transportion. These include the unavoidable trade-offs that are usually considered to be environmentally negative. A typical reaction is to suggest, as if location were completely arbitrary, that a particular operation be done elsewhere. "Why here?" is always a good question and "because" is usually an unsatisfactory answer.

One example of a locational conflict derives from the fact that there are abundant cinder deposits near Flagstaff (Figure 1) and none in the Phoenix region (See Welty and Spencer-this volume). A variety of construction blocks is made in Phoenix for the local market. One, called cinder block, uses some Flagstaff area red cinders. A competitor, wanting to develop an alternative cinder block for architects, decided to use black cinders if he could find an available deposit. The search led him to the very fringes of the San Francisco Volcanic Field, 20-25 miles northeast of Flagstaff, where he found a deposit of black cinders on private land. This particular deposit happened to be adjacent to Merriam Crater, a place where the lunar astronauts trained. A rumor began to circulate to the effect that someone was going to mine this very special cinder cone! The subject was placed on the agenda of a regular meeting of the Governor's Commission on Arizona Environment to be held at Flagstaff.

The thrust of the presentation was that something was wrong when a person could just come in and mine "common" cinders anywhere! Why open a new pit when there were so many others already in existence? Obviously, there had to be some kind of local control to oversee this type of uncalled-for development. Up to this point, cinders had been treated generically - they were all the same. From the floor, a representative of the U.S. Bureau of Mines asked if the presenter had talked with the pit owner to see what he had in mind? The answer was negative. The USBM person then asked what the cinder color was in all of these existing cinder pits? "Red" was the response. Well, the interloper from Phoenix wanted black cinders. Could the presenter tell us where to find black cinders and comment on how common they might be? Again, a negative response. The point was made that the cinder seeker from Phoenix was not as irresponsible as casual observers and critics had made him out to be.

Those whose task it is to find mineral and energy resources, especially those resources that are buried and not directly observable, are understandably concerned about land classifications that stymie the search. It would seem as though the ultimate user of materials, the general public, also has a vested interest in maximizing opportunities for search and discovery. We hear the expression "special interests" with regularity. With regard to the seekers of mineral and energy resources, they could not function if there wasn't a larger "general interest" to be served.

An example of the surface-subsurface dichotomy is the position of the earlier established Petrified Forest National Park with respect to subsurface resources of potash discovered later. The Park is above a portion of the Holbrook evaporite basin. The initial Monument was created in 1906, the first salt encountered by drilling in about 1920, and the associated potash (KCL) suspected in 1951, was confirmed by drilling in 1964. This 1964 confirmation initiated an intensive search for economic deposits of potash (Figure 1). More than 100 holes were drilled, many of which encountered potash (Peirce and Scurlock, 1972). Potash was found on two sides of the Park therefore it is believed to be continuous beneath it (Peirce, 1969). Deposits judged to be economic have not been outlined therefore they are classed as potential resources of possible future interest. There is no intent here to in any way downplay the fabulous Park. Rather, these comments are presented merely as a case history that illustrates the difficulty in knowing, at any given time and place, what secrets the earth holds beneath its surface.

Market Stability

Markets for IM vary according to the commodity, economic conditions, and competitive developments.

An example of production longevity is the special bentonite clay that occurs in southern Apache county in the plateau province of northeastern Arizona (Figure 1). This clay has, it is believed, been in continuous production since 1925. Like the Bowie zeolite, it is an alteration product of vitric ash. The raw clay is stripped of its overburden and shipped out of state for processing into desiccants, thickeners, and acid-activated clay products (See Eyde and Eyde - this volume).

Over sixty years ago Arizona led the nation in the production of chrysotile asbestos. Its low iron content made it especially valuable for certain electrical applications (covering cables, etc.). Until recently, it was in almost continuous production, an estimated 160 deposits supplying the demand through the years. Today, for liability (not scientific) reasons, the industry is inoperative in Arizona (Peirce, 1983; See Ross - this volume).

There is a group of IM that have been sporadically produced. These include barite, fluorite, diatomite, feldspar, quartz, mica, etc. For the most part these, in relatively small quantities, have been exported for use elsewhere as conditions permitted.

THE FUTURE

Arizona, like a magnet, attracts people. Population growth seems inevitable, as does the industrial growth that must occur if people are to find employment. Whether or not there will be significant expansion in basic IM industries depends upon growth rate. Arizona has the potential for development of additional IM deposits through new discoveries and changes in circumstances that affect development of deposits already known.

Because of geologic variety and complexity, Arizona's major mineral production and development potential seem vested in the southwestern half of the State - the Basin and Range geologic province. Many geologic mysteries remain and inherent in these are mineral resource discovery opportunities. Opportunities must be identified if the State and nation are to continue to be supplied with the basic ingredients that have come to be the foundation of modern civilization (See Reynolds and Peirce - this volume).

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The Geology of Cement Raw Materials: Pacific Southwest

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ABSTRACT

Cement raw materials used in southern California and Arizona cement plants occur in a wide variety of geologic environments. Limestone, the primary material making up 75-80% of the raw materials mix used in cement manufacture, is mined solely from Paleozoic Era deposits. During this time, 570-245 million years ago, vastly more limestone was formed in California and Arizona than at any other time (continent was in southern latitudes).

The general geology of each limestone deposit associated with the eight southern California and two Arizona cement plants will be reviewed. Many of these deposits are geologically complex, having been subjected to Mesozoic deformation, metamorphism and instrusive events, along with Cenozoic uplift and deformation.

All of the cement plants in this region require the use of secondary additives in order to meet the chemical requirements for cement. The kinds of additives vary greatly, depending upon the chemistry of the limestone deposit, cement specifications, and the cement manufacturing process. In some cases, clay deposits with suitable chemistry on or near the limestone sources are utilized. Where alkali limitations or need for alumina-rich materials exist, then specialty clay deposits are used. Iron-rich sources in the region include iron ore deposits and slag or mill scale from local steel mills. The geologic setting and location of these additives, along with gypsum and silica-rich deposits presently in use, will be mentioned.

INTRODUCTION

An understanding of both regional and local geologic habit of cement raw material deposits is not only essential for exploration of undeveloped deposits, but where complexity exists, also during development and production for purposes of quality, cost and long-range mine planning.

Cement raw materials utilized in southern California and Arizona cement plants are widely distributed geographically and occur in a variety of geological environments. Limestone, the primary material making up 75-80 percent of the raw materials mix for cement manufacture, is mined solely from Paleozoic Era deposits in this region. Many of these deposits are geologically complex, having been subjected to Mesozoic deformation, metamorphic and intrusive events, along with Cenozoic uplift and deformation. The remaining 20-25 percent of the mix, which consists of additives such as silica, alumina, gypsum, and iron-oxide-containing materials, occurs either in the limestone, in separate deposits of diverse ages, or as man-made waste materials.

The information presented here is based upon both published and unpublished sources. It is common industry practice to treat details as proprietary thus this presentation is only a general overview of the subject.

There are eight cement manufacturing facilities in southern California and two in Arizona. Total annual cement production capacity for southern California is 8,200,000 tons, and for Arizona is 1,750,000 tons, a total of 9,950,000 tons of annual cement plant capacity (Pit and Quarry data). In 1984, portland cement shipments, by destination, were 5,552,400 tons for southern California and 1,821,300 tons for Arizona, totaling 7,373,700 tons for the region (U.S. Bureau of Mines data). Of this total, about 15 percent, or about 1,100,000 tons, was imported through the Nogales, Arizona, San Diego, and Los Angeles ports of entry. If the imported quantity is subtracted from the total shipments, it is estimated that about 6,270,000 tons of cement, representing about 63 percent of capacity, (Table 1) were produced within the region.

To provide an idea of the quantities of limestone and additives required for this production, the following assumptions are made: (1) it takes about 1.50-1.75 tons of raw material to make 1 ton of cement, and (2) 80 percent of the raw material feed mix is limestone and 20 percent is substances containing silica, alumina, sulfate, and iron. This results, based on the 1.75 factor, in the annual utilization of 10,972,000 tons of raw material feed of which 8,777,600 tons is limestone and 2,194,400 tons is additives.

Portland cement is a standardized product, the standards being based upon criteria developed by the American Society of Testing and Materials (ASTM). Specifications include chemical composition, physical performance, and fineness of the cement. Regarding chemis-

Oro Grande and the Black Mountain-Sidewinder Mountain areas located 16 miles east-northeast of Victorville. These limestone deposits have supplied the Los Angeles area market for more than 100 years and presently support two cement plants, Southwestern's Black Mountain plant and Gifford-Hill's Oro Grande plant.

The limestone deposits occur in large, moderately to severely metamorphosed roof pendants more or less surrounded by granitic rocks. In the late Paleozoic (?) Oro Grande series, utilized by Gifford-Hill at Oro Grande and by Southwestern at Black Mountain, crystalline limestones are interbedded with thick units of quartzite and mica schist. The carbonate units are commonly several hundred feet thick and several thousand feet in exposed length. The limestones are medium to coarse grained and vary from white to dark blue-gray. The regional trend of these deposits in the area north of Victorville is northwest and is cut by east-trending cross faults. This northwest trend is further disrupted by smaller strike and transverse faults and by tight, usually ruptured minor folds. Granitic intrusions cut the metasedimentary section and increase the complexity. The Oro Grande series has been subjected to at least two major episodes of deformation that included regional metamorphism. In all deposits, limestones have become marbles, pelites mica schists, and sandstones and cherts quartzites. Contact metamporphism has, in some instances, produced high grade metamorphic mineral assemblages. Recent evidence suggests that this sedimentary sequence is part of a stratigraphic section that correlates with Paleozoic marine sedimentary rocks of the southern Great Basin.

Thought to be a part of the Oro Grande sequence, the Permian Fairview Valley Formation is another source of limestone for cement in this district. At Southwestern's Black Mountain deposit, the area is underlain by a 1,350 foot thick limestone conglomerate member of this formation. The limestone occupies the axial part of a tightly folded, symmetrical northwest trending syncline. Cobbles, boulders and pebbles of dark gray, pinkish gray and black limestone, with minor white to gray dolomitic limestone cobbles and pebbles, comprise more than 95 percent of the clasts in the conglomerate. Clasts of brown chert make up the remainder of the clastic fraction. The matrix consists of fine-grained light to dark gray limestone with local siliceous and hydrothermally altered patches. The clasts are generally subrounded to well-rounded but occasionally angular to subangular. Bedding is ill-defined except where the conglomerate interfingers with a hornfels unit. The Fairview Valley Formation lies unconformably on massively bedded limestone and quartzites of the Oro Grande sequence and has been intruded and overlapped by volcanic rocks of the Triassic (?) Sidewinder volcanic series. The limestone conglomerate, although not a pure limestone, is sufficiently uniform in chemical composition to be usable in cement manufacture. Silica content is the primary variable and depends upon proportions of chert clasts and interstitial silicification.

Riverside-Colton District

The limestone deposits closest to the Los Angeles market area presently being used for cement manufacture are those of the eastern Jurupa Mountains located between the cities of Riverside and San Bernardino. These deposits support California Portland Cement Company's (a division of Calmat) Colton plant, located about 5 miles southwest of San Bernardino as well as Gifford Hill's Crestmore plant about 3 miles northwest of Riverside. The limestone is exposed in a group of hills and occurs as roof pendants in granitic rock. Some interbedding with dolomite and mica schist occurs.

The Slover Mountain deposit, located adjacent to California Portland's Colton plant, is part of a roof pendant of Paleozoic (?) crystalline limestone in granodiorite. The limestone varies from a high grade (99% $CaCO_3$) coarse crystalline white variety to a finer grained blue-gray to white variety with a lesser percentage of $CaCO_3$. Small, but minor disseminated flakes of graphite are widespread. Small, contorted lenses of mica schist also exist throughout. Limestone strata are obscure, trending north-northeast and dipping to the east. The northwestern part of the deposit is cut by dikes of aplite, pegmatite and granodiorite varying from a few inches to more than six feet in width.

At Gifford-Hill's Crestmore operation, limestone is mined underground from two limestone units, a lower 400-foot thick Chino Formation and an upper Sky Blue Formation more than 500 feet thick. The Crestmore operation produces the only white cement in the region and rock from either limestone unit is suitable for its manufacture. The limestone is coarsely crystalline and white to blue-gray. The limestone units are separated by gneissic hornfelses and schists that have been largely displaced by a sill-like mass of quartz diorite. These deposits, as exposed in original surface quarries, because of the occurrence of a great variety of exotic contact-metamorphic minerals, have received much attention in the past.

Tehachapi Mountains, Kern District

This area, approximately 60-70 miles north of Los Angeles, supports three cement plants: California Portland's Mojave plant, Monolith's plant near Tehachapi, and General Portland's Lebec plant. The extensive carbonate deposits in this district occur either as

Table 1. *Cement data (tons) for 1984 - southern California and Arizona (sources: Pit and Quarry; U.S. Bureau of Mines)*

	PRODUCTION CAPACITY	
Southern California		8,200,000
Arizona		1,750,000
	TOTAL	9,950,000
	CEMENT SHIPMENTS	
Southern California		5,552,400
Arizona		1,821,300
	TOTAL	7,373,700
Foreign share		(1,100,000)
Domestic total		6,273,700

try, the ordinary "commercial" or STM Type I cement in this region has the following typical broad composition: CaO (60-67%), SiO_2 (19-24%), Al_2O_3 (4-9%), Fe_2O_3 (1.6-6%), MgO (not more than 5%), SO_3 (up to 3%), $K_2O + Na_2O$ (.65%). Special purpose cements are more stringent in their chemical requirements. Well-known deleterious ingredients, when present in excess, include MgO, SO_3, alkalies (K_2O and Na_2O), and phosphorous. With the advent of the dry process, preheater precalciner cement plant, volatile compounds such as chlorides, fluorides and sulfur also are considered deleterious to the cement process, thus the existence and/or distribution of these components in the various deposits must also be determined and evaluated.

The raw materials in cement manufacture are combined in the proper proportions, ground to a fine powder in the dry process, then heated, first to calcination, then to fusion, in a rotary kiln. The ingredients combine to form desired crystalline or glassy substances and a "clinker" is produced. Clinker, when fine ground with 3 to 5% gypsum to control setting time, is portland cement.

The cement company geologist, thus, is concerned with a lime (CaO) source that, in this region, is provided by limestones. The aluminum silicates, iron aluminum silicates and silica, occur as clays or shales, quartz and quartz sands, feldspars, iron oxides and hydroxide, and combinations of these as igneous or metamorphic rocks. The deleterious elements of each is also considered. The simplest raw material feed mix would be a single rock unit such as a shaley limestone having all of the proper components. This, a natural cement rock, is not known to exist in the region. A two component raw feed mix would be: (1) limestone, and (2) iron-bearing clay or intermediate igneous or volcanic rock. A three component mix: (1) limestone, (2) clay, igneous or volcanic rock, and (3) silica (quartz, sand). A four component mix: (1) limestone, (2) clay, igneous or volcanic rock, (3) silica, and (4) high-iron ore or industrial by-product: or (1) siliceous limestone, (2) clay, (3) high alumina clay or bauxite, and (4) iron ore or industrial by-product. The variety of components needed in a raw feed mix directly relates to the chemistry and geology of a given limestone deposit. Other deposit considerations include costs related to location, reserves, materials handling characteristics, plant design and operating practices of plant operations personnel etc. The use of coal as a primary fuel in cement manufacture provides coal ash with varing proportions of SiO_2, Al_2O_3, and Fe_2O_3. This adds further complexity when evaluating a raw feed mix.

LIMESTONE UTILIZATION

The limestone deposits presently being exploited for cement manufacture in southern California and Arizona occur solely in Paleozoic Era formations. During this time, when the landmass was in equatorial regions, vastly more limestone was formed than at other times.

The limestone formations in southern California used for cement are discussed as districts, and located on Figure 1.

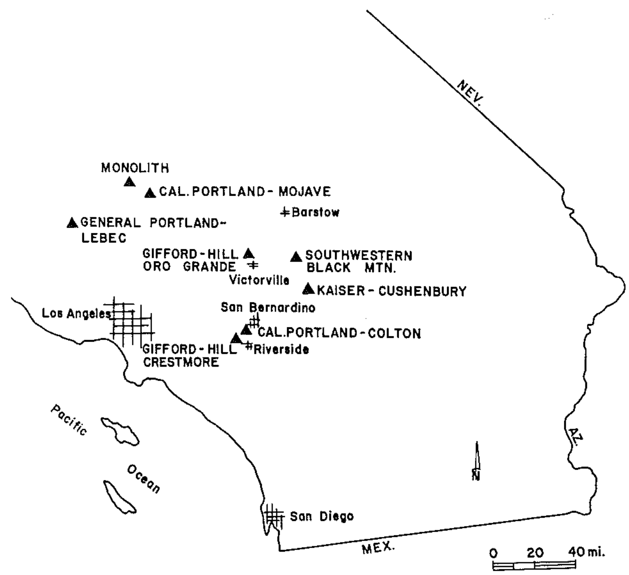

Figure 1. *Southern California cement plants.*

Victorville - Oro Grande District

The Victorville area is located about 90 miles N.E. of Los Angeles. The principal exploited deposits are in the hills just east of the city of Victorville, the Quartzite Mountain and Sparkule Hill vicinities east of roof pendants or as elongate layers partly encased in younger intrusives varying from very basic to highly silicic. The limestone deposits occur either alone or interbedded with mica schist and quartzite in sequences referred to as either the Bean Canyon formation or the Kernville Series. In the absence of fossils these units are considered to be late Paleozoic or early Mesozoic in age. The limestone is commonly coarse grained with colors ranging from white to blue-gray. Dolomite and dolomitic limestone is present in the form of isolated pockets and/or massive interbeds. Smaller granitic intrusions are common within individual limestone bodies and silica and silicate minerals produced by contact metamorphism add to the complexity of these deposits.

Cushenbury District

Limestone deposits in this area, located approximately 25 miles southwest of Victorville, are utilized at Kaiser Cement's Cushenbury plant. The Cushenbury limestone deposit is part of a large roof pendant of upper Precambrian to upper Paleozoic metasedimentary rocks uplifted and exposed along the north flank of the San Bernardino Mountains during late Cenozoic time. The deposit contains limestone and dolomites of Mississippian and Pennsylvanian ages. The limestone is locally referred to as the Furance formation, however, typical Great-Basin stratigraphic nomenclature is currently being considered for this pre-Mesozoic carbonate sequence. The carbonate rocks have generally been regionally metamorphosed. Moderately high grade metamorphic facies with local increases in grade and character of metamorphism occur adjacent to intrusive dikes, sills and stocks of aplite, granodiorite and biotite quartz monzonite. The limestone produced from the quarry is typically recrystallized, medium to coarse grained calcite marbles of varying purity. Even though these carbonate rocks have been recrystallized from limestones to marbles, the original sedimentary structures have been retained in many of the individual rock units. Surface mapping has resulted in the identification of at least 16 different limestone units, with differentiation based upon chemical composition, color, crystal size and stratigraphic position. The effects of metamorphism and intrusion on the original chemical composition resulted in the replacement of original carbonate with varying amounts of iron, silica, aluminum and alkali-bearing minerals.

The deposit is located at the junction of the northwest trending Helendale right lateral strike-slip fault, and the east-west trending Furnace reserve (thrust) fault. The thrust fault zone is exposed as a series of clay layers one to two feet thick and two to three feet apart, in a zone 20 to 40 feet thick. Two other fault systems have been identified, high angle, east-west trending reverse faults, and high angle normal faults with east-west to northeast trends.

Arizona

Two cement plants operate in Arizona: Arizona Portland's Rillito plant located about 18 miles northwest of Tucson, and Gifford-Hill's Clarkdale plant in the central part of the State approximately 95 miles north of Phoenix. These operations are located on Figure 2. Limestones utilized at these plants are from Paleozoic carbonate units containing limestone, dolomite, and chert along with megafossils indicative of shallow, clear, marine environments of deposition.

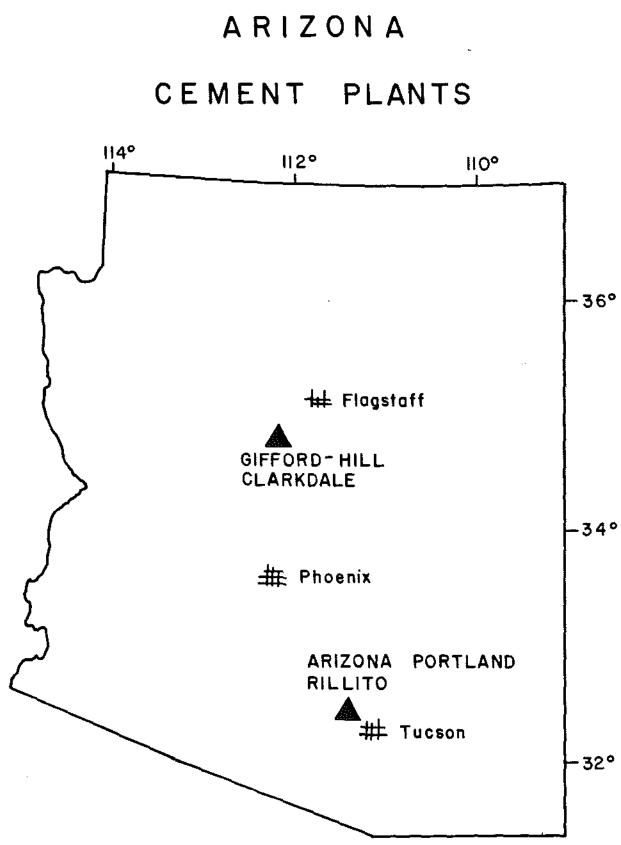

Figure 2. Arizona cement plants.

Arizona Portland's Rillito plant is supplied largely with limestone from their Twin Peaks deposit located about 4 miles southeast of the plant. Limestone formations utilized for cement include the Devonian Martin Formation, Mississippian Escabrosa Limestone and Pennsylvanian Horquilla Limestone.

The Horquilla Limestone typically consists of fine grained, light yellowish gray limestone interbedded with shaley or silty limestone. Thin beds of siltstone, shale, and chert are also scattered through the formation. The Escabrosa Limestone consists of white to light gray limestone in the upper and middle parts and light to dark gray dolomite and limestone in the lower section. The Martin Formation consists mostly of very fine to fine grained, laminated to thin bedded and medium dark gray to olive gray, dolomite. Sandstone and shaley limestone beds, however, are scattered through the formation.

Limestone for Gifford-Hill's Clarkdale plant comes largely from the Mississippian Redwall Limestone. The Redwall Limestone is a massively bedded, often cherty, gray and coarsely crystalline rock with few impurities.

A common thread that runs through all of these deposits is the complexity involved in comprehending rock composition such that the mined rock will (1) meet raw feed specifications, (2) be consistent with day to day raw feed chemistry and (3) meet long term mine planning needs for the deposit. Variations in these limestone deposits result from (1) primary variations caused during deposition, either vertically or laterally, (2) secondary chemical changes associated with regional and/or contact metamorphism, and (3) structural activity that causes folding and/or faulting typically resulting in repetition of units, termination of deposits, radical differences in dip directions etc.

Table 2 summarizes the limestone formations used by each producer in southern California and Arizona.

Table 2. *Limestone-bearing formations utilized by cement plants - southern California and Arizona*

SOUTHERN CALIFORNIA

Plant-Annual Cement Capacity	Stratigraphic Assoc., Deposit Type and/or Provincial Location
1. California Portland - Mojave 1,400,000 tons	Bean Canyon/Kernville Series (roof pendant)
2. California Portland - Colton 750,000 tons	Slover Mountain (roof pendant)
3. General Portland - Lebec 610,000 tons	Bean Canyon/Kernville Series (roof pendant)
4. Gifford-Hill - Crestmore 840,000 ton (includes white cement)	Chino and Sky Blue (roof pendant)
5. Gifford-Hill - Oro Grande 1,100,000 tons	Oro Grande Series (roof pendant - Basin and Range)
6. Kaiser Cement - Cushenbury 1,600,000 tons	Furnace (roof pendant - Basin and Range)
7. Monolith - Tehachapi 500,000 tons	Bean Canyon/Kernville Series (roof pendant)
8. Southwestern - Black Mountain 1,400,000 tons	Fairview Valley and Oro Grande Series (roof pendant - Basin and Range)

ARIZONA

Plant-Annual Cement Capacity	Stratigraphic Assoc., Deposit Type and/or Provincial Location
1. Arizona Portland - Rillito 1,150,000 tons	Martin, Escabrosa, and Horquilla (Fault block - Basin and Range)
2. Gifford-Hill - Clarkdale 600,000 tons	Martin and Redwall (Outcrop belt - Transition Zone)

ADDITIVES

No discussion of cement raw materials is complete without mentioning the additives utilized to provide silica, aluminum and iron to the raw material feed stock, along with gypsum which is added to the clinker for the finish grind. The usage of silica, aluminum and iron additives is usually based upon the chemistry of the particular limestone, and cement specifications. Approximately 3-5% gypsum is added in order to control or retard the set time of the final cement product. Rather than discuss each additive source for each producer in the region, only selected deposits will be mentioned. The general types of additives used by each plant are summarized in Table 3. The following is a discussion of selected deposits with locations shown on Figure 3.

Table 3. *Raw materials additives utilized by cement plants - southern California and Arizona*

SOUTHERN CALIFORNIA

Plant	Additives and Source	
1. California Portland - Mojave	shale silica iron	- plant - gold mine tailings
2. California Portland - Colton	clay silica iron	
3. General Portland - Lebec	unknown	
4. Gifford-Hill - Crest	shale clay iron	 - Corona
5. Gifford-Hill - Oro Grande	shale clay iron	
6. Kaiser Cement - Cushenbury	clay iron	- Acton - Fontana
7. Monolith - Tehachapi	clay	- plant
8. Southwestern - Black Mountain	silica iron	- Oro Grande series quartzite - altered dacite

ARIZONA

Plant	Additives and Source	
1. Arizona Portland - Rillito	clay silica iron	- Vail - plant, quartzite - iron ore - California
2. Gifford-Hill - Clarkdale	clay volc.	- plant - plant

Clay

The Alberhill-Corona clay deposits, located in the western Riverside County area of southern California, about 45 miles southeast of Los Angeles, have provided silica, aluminum, and iron-bearing clays to the cement plants in this region. The clays in this district are of two origins - residual and

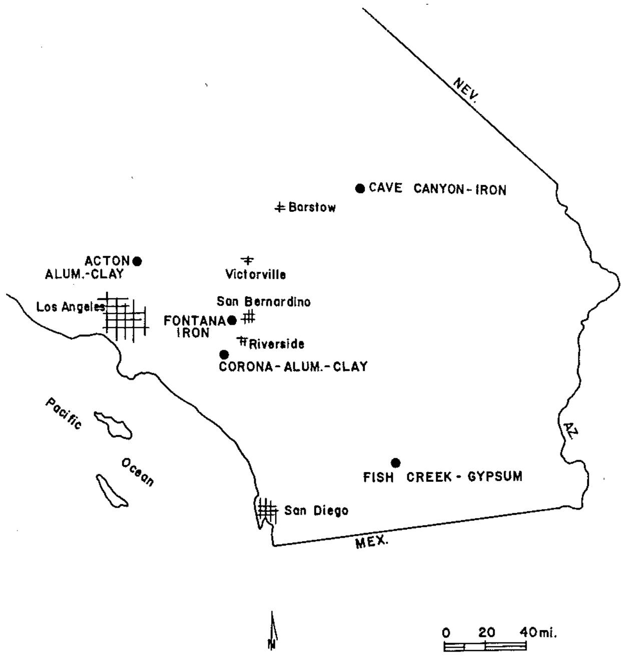

Figure 3. *Southern California cement raw-material additives.*

sedimentary. The residual types have developed in place by subaerial chemical weathering of aluminum-rich rocks including quartz latite porphyry, quartz diorite, volcanic latite and andesite and slates. The sedimentary clays and clay shales utilized are locally part of the Paleocene Silverado Formation. The formation consists primarily of brown to gray clastics that include conglomerates, sandstones, siltstones, and claystones.

The nonmarine lower member contains large quantities of alumina-rich clay and small amounts of bauxitic clay. Other clay materials consist of reddish-brown pisolitic sandy clay, a read mottled clay, and a white to brownish conchoidally-fracturing kaolinite. Clay beds are 1-10 feet thick, and generally have little continuity. Thrust faulting and multiple episodes of normal and reverse faulting resulted in vertical beds and discontinuous clay layers. It is necessary to mine selectively and to blend in order to obtain consistent quality control.

In addition to supplying clay to cement plants in southern California, the Corona clay deposits have principally been a source for the clay manufacturing industry. The principal reasons for utilizing these deposits for cement have been the relatively high aluminum content and low total alkali values. A typical analysis is: SiO_2 60-65, Al_2O_3 25-30%, Fe_2O_3 5-10% and total alkalies less than 1%.

Another alumina-rich clay deposit presently being used in southern California by Kaiser Cement Corp. is located in the San Gabriel Mountains approximately 40 miles north of Los Angeles, near the town of Acton. The red to yellowish-orange clay results from the weathering of a Precambrian pluton of anorthosite. The anorthosite is an unusual light gray to white, equigranular, medium to coarse grained, brittle rock composed essentially of the one feldspar mineral, plagioclase (andesine). The clay deposits occur either as residual or as recent colluvial material exposed on upland slopes. A typical analysis of this material is: SiO_2 46%, Fe_2O_3 11%, Al_2O_3 35%, and total alkalies 1-1.5%.

In addition to the cited "high" aluminum clays, some producers also use a "common" clay or clay shale, usually located near the cement plant, for a source of silica, alumina and iron. These deposits are either young alluvial clays or older clay shales that are associated with the limestone deposits. As an example, Arizona Portland Cement's Rillito operation hauls a clay-shale from the Oligocene Pantano Formation that crops out about 20 miles southeast of Tucson. A typical analysis is: SiO_2 53.8%, Al_2O_3 17.6%, Fe_2O_3 4.8%, Na_2O 0.3%, K_2O 3.7%, SO_3 .48%, etc. (personal communication, Jerry Boyett - Plant Chemist). This source also is widely used in the manufacture of red brick in both Tucson and Phoenix (a haul distance of about 150 miles).

IRON

Some of the cement manufacturers prefer to use iron-rich materials in order to attain the required iron proportion in the raw material feed mix. By far the purest iron-bearing substance presently being utilized is "man-made" mill scale or sinter mix from Kaisser Steel's (now closed) Fontana Mill near San Bernardino in southern California. The material is +90% Fe_2O_3, with the remainder being SiO_2 and Al_2O_3.

The Cave Canyon iron ore deposit, owned by California Portland Cement Co. and located 50 miles east of Barstow, is typical of an iron-rich material for cement manufacture. The iron minerals, magnetite and hematite with subordinate limonite, occur in bodies that are enclosed in a complex of metamorphosed dolomites, tactites and granitics. In general, the deposits and surrounding units trend east-northeast with intricate faulting, brecciation, and simple to complex folding being characteristic. This iron ore deposit is considered to be the second largest in southern California (second to Kaiser Steel's Eagle Mountain deposit) with proven reserves of more than 10 million tons. Typical ore assays average 90% Fe_2O_3, the remainder being SiO_2 and Al_2O_3.

Silica

In Arizona, Arizona Portland Cement uses quartzite from the Cambrian Abrigo Formation, from areas close to their limestone deposit at Twin Peaks. This formation contains interbedded mudstone, siltstone, sandstone and quartzite. Colors range from reddish brown to yellowish light gray. The quartzite is composed of subangular to subrounded quartz plus lesser amounts of feldspar.

Quartzite from the Oro Grande series is utilized by Southwestern Portland at their Black Mountain Cement Plant. The quartzite, quarried from locations close to the limestone quarry, is characteristically massive, and pinkish white to brown in color. Quartzite units occur as interbeds with other units of the Oro Grande series, such as limestone, hornfels and schists. Faults often disrupt continuity.

The use of quartzites is one case where the chemistry of a raw materials additive may be satisfactory but not useful for physical reasons. Quartzites, for example, are much harder than limestones. This can result in either different sizing during grinding, or, added grinding costs during the raw material grinding process. A Bond grindability test provides an indication of the power required to grind a material to a desired fineness at a given capacity. This test affords a means by which quartzites can be selected.

Gypsum

The Fish Creek Mountains gypsum deposits constitute the largest reserves of this commodity in southern California. These deposits are located in extreme eastern Imperial County about 70 mils east of San Diego. The gypsum mined from these deposits is primarily used in the manufacture of gypsum wallboard, however, about 20% of the production from this area is used in cement manufacture and supplies most southern California cement plants. The deposit, consisting of up to 200 feet of massive rock gypsum, lies at the top of the Miocene Split Mountain Formation. Anhydrite is present as erratic lenses in the gypsum while interbedded clay occurs near the top and bottom contacts of the deposit. Minor impurities in the gypsum include varying and random concentrations of chloride salts and fine-grained, opaque manganese and iron oxides. The gypsum outcrops as erosional remnants, preserved in a shallow synclinal basin with bedding dipping toward the synclinal axis at 15-30 degrees. The suggested origin is rapid evaporation in seacoast lagoons with periodic influx of sea water. Several parties control portions of the deposit. U.S. Gypsum Co. owns the most significant part and operates the gypsum quarry that provides the majority of the Portland Cement gypsum production. California Portland Cement Co. holds mining claims adjacent to U.S.G.'s holdings and intermittently mines the gypsum for use in their southern California cement plants. National Gypsum controls a large undeveloped deposit south of California Portland's holdings. Gypsum for the two Arizona plants comes from Pliocene deposits located within their respective regions. These deposits represent conditions of evaporation in local, nonmarine basins.

SUMMARY AND ACKNOWLEDGMENTS

The geology of limestone deposits used for cement manufacture in southern California and Arizona is quite complex. The southern California deposits are metasedimentary roof pendants of Paleozoic limestone-bearing strata. The Arizona deposits, on the other hand, are of relatively unaltered Paleozoic formations that contain abundant limestones. Along with the usual variable nature of flat-lying limestone deposits resulting from slight lateral changes and layering, the California deposits have been subjected to Mesozoic deformation, intrusion and metamorphism, and Cenozoic deformation. The use of specific additives depends upon the chemistry of individual limestone deposits, cement specifications, costs, and the cement plant operation. Clays and shales provide the majority of iron, silica and aluminum additives to the raw material feedstock. These materials are either located near or actually associated with the limestone deposits. Aluminum rich materials are sometimes obtained from clay deposits rich in aluminum, while iron-rich materials are obtained from steel mill slag and mill scale stockpiles that are of very high purity or lower purity iron ore deposits. High purity silica is used from selected quartzite deposits.

I thank Doug MacIver with Southwestern Portland Cement, John Rains with California Portland Cement and Steve Greenspan with Pacific Clay Products for providing input and comments. I also acknowledge M. J. Bishop, Manager, Mineral Resources, Kaiser Cement Corp. for his comments and allowing publication of this paper.

Natural Lightweight Aggregates of the Southwest

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ABSTRACT

The southwestern United States has an abundance of natural lightweight aggregate (NLA) deposits of volcanic origin that are being used in the construction industry within the region. New Mexico, Arizona, Nevada and California utilize NLA in portland cement concrete and concrete masonry units for weight reduction and related economic reasons.

The geological environment of the western United States is amenable to the occurrence of natural lightweight rocks because it contains Tertiary and Quaternary volcanic products that include low-density glass and vesicular material. There are two major classical types of natural lightweight materials of igneous origin; pumice and cinder. These account for the vast majority of volcanic rocks that are presently utilized as NLA. Pumice is an ejecta product generally found as part of tuffaceous units associated with nearby siliceous volcanic centers. Cinder, also an ejecta product, is associated with mafic volcanics and is most often found as a cinder cone. Both are highly vesicular. A third type of natural lightweight material, though also associated with siliceous volcanics, is less vesicular than pumice. It is best described as being a slightly pumiceous rhyolite or rhyolite-tuff breccia that occurs as a siliceous dome or tuff unit that is most likely to be glassy.

Uses of these natural lightweight rocks center on the construction industry where they are utilized in lightweight portland cement concrete and lightweight concrete masonry units. The major reason for usage in portland cement concrete is cost saving effected by weight reduction in high-rise construction. The major usage in concrete masonry units, or "block", is for weight reduction that enables a mason to lay more lock.

INTRODUCTION

Natural lightweight aggregates (NLA) described here are low density, lightweight volcanic rocks. They are restricted in their distribution to the geologic environment of the western United States and consist of pumice, volcanic cinder, and pumiceous rhyolite. The purpose of this paper is to briefly review the current status and use of these materials in the southwest.

Lightweight aggregate up to approximately one inch in size are utilized primarily in the construction industry for weight reduction and insulation purposes. Pumice and volcanic cinder have long been utilized for these purposes, whereas pumiceous rhyolite is a relative newcomer.

Other lightweight aggregates utilized throughout the country, but not discussed in this paper, include the manufactured lightweights such as expanded clay or shale and the ultra lightweights, perlite and vermiculite. Expanded clays and shales, utilized mostly in the eastern portion of the country, are manufactured by heating certain clays or shales until they become plastic thus allowing the included volatiles to expand. When cooled, the result is a frothy, lightweight, ceramic-like pellet. Perlite and vermiculite are also expanded by heating but generally result in an ultra lightweight material having very little structural strength.

ECONOMICS AND UTILIZATION

In analyzing the economics of using NLA the prime consideration is transportation cost. Because they occur in the west, they are used in the west. Although the manufactured lightweights such as the expandable clays and shales are more evenly distributed throughout the United States, because they are energy intensive, cannot compete in areas where NLA is found. Because of fuel costs, many manufactured-lightweight-aggregate plants closed following the energy crisis of the seventies. This led to a renewed interest in western NLA. NLA deposits that haven't been active in years are undergoing reevaluation, and previously unrecognized natural lightweight rocks are being evaluated and developed.

The use of NLA can be traced back to the days of the Roman Empire when pumice was extensively used in the Mediterranean region. Pumice and volcanic cinder have been utilized in construction in the western United States since near the turn of the century and pumice from Greece has been imported on the east coast of the U.S. for some time.

The principal uses of lightweight aggregates are in the construction industry, primarily in applications for lightweight portland cement concrete and for lightweight concrete masonry units.

Portland Cement Concrete

In lightweight portland cement concrete, lightweight aggregates are utilized primarily for weight reduction in high-rise construction. A lightweight concrete will weigh approximately 25% less than normal weight concrete utilizing common aggregates such as sand and gravel. This translates into cost savings as there is a parallel reduction in the mass of footings, structural members and reinforcement within the building. A 24-story concrete building utilizing lightweight aggregates may have the same dead weight as a comparable building 20 stories high utilizing normal weight aggregates.

In addition to weight reduction, lightweight aggregates increase the insulation, thus fire retardation effect, of concrete. In some cities in the Southwest local codes allow a lightweight aggregate to be utilized not for its weight reduction but for its effectiveness as a fire retarder, thereby reducing floor thickness requirements.

Concrete Masonry Units

Concrete masonry units, commonly referred to as "block" in the building trades, are affected by the same properties of lightweight aggregates as is portland cement concrete, namely weight reduction, insulation and fire retardation. In the Southwest where NLA is available at relatively low-cost, the most important use is as a weight reducer in the individual masonry units. A mason can lay more lightweight blocks during the course of a day than he can heavier blocks made from ordinary sand and gravel. This translates into increased productivity and related cost savings.

Physical and Chemical Properties

As with many industrial mineral commodities, a thorough evaluation of a potential NLA resource entails an evaluation of how its physical and chemical properties affect application. The important properties of a NLA for use in portland cement concrete or concrete masonry units include unit weight, specific gravity, absorption, hardness, durability, chemistry (including reactivity potential), cleanliness, expansion characteristics, organic impurities and particle size distribution.

The characteristics of the final lightweight concrete product are highly dependent on these individual aggregate properties. Most important are the weight and strength characteristics of the final product, but other considerations include shrinkage, durability, thermal properties, color, and placement characteristics when fresh, such as pumpability.

In some instances processing of the aggregate influences its characteristics. Proper screening will determine particle size distribution and washing may eliminate undesirable ingredients. In most cases, however, individual properties are inherent in the rock, having been determined by the genetic environment, melt composition, weathering history, etc.

A more complete discussion of individual aggregate properties, etc. is beyond the scope of this paper. Testing of lightweight aggregate, portland cement concrete and concrete masonry units, is outlined in great detail in various American Society for Testing and Materials (ASTM) specifications that are updated yearly. The American Concrete Institute (ACI) publishes standards for the design and evaluation of lightweight portland cement concrete. Numerous professional and trade publications of the engineering or construction materials professions contain articles that deal with individual properties of both aggregates and their end products.

GEOLOGY AND DESCRIPTION OF THE NATURAL LIGHTWEIGHT AGGREGATES

Figure 1 shows the distribution of Tertiary, and younger, volcanic rocks of the Southwest. All of the NLA are volcanic in origin and most are Quaternary or late Tertiary in age. In general, the younger host rocks yield the higher quality lightweight aggregate because the younger volcanics are usually less indurated or weathered. Also, with age comes increasing devitrification of the glassy phases, which tends to densify the rock.

The method of emplacement or formation of young volcanic rocks suitable for lightweight aggregates must include vesiculation of aphanitic or glassy material. Cooling of the melt must be rapid and accompanied by volatile expansion. The composition of the melt also influences the end-product rock type, be it pumice, volcanic cinder or a close derivative of either. Silicic lavas give rise to pumice and pumiceous rhyolite, whereas mafic lavas yield volcanic cinders. The method of emplacement usually is pyroclastic, which forms tuffs, breccias or cones.

The geology of the three most common types of natural lightweight rocks pumice, volcanic cinder and pumiceous rhyolite is discussed in the following paragraphs, along with comments on the particular end-product application of each aggregate.

Pumice

Pumice is a highly vesicular, glassy volcanic material, usually white to yellow in

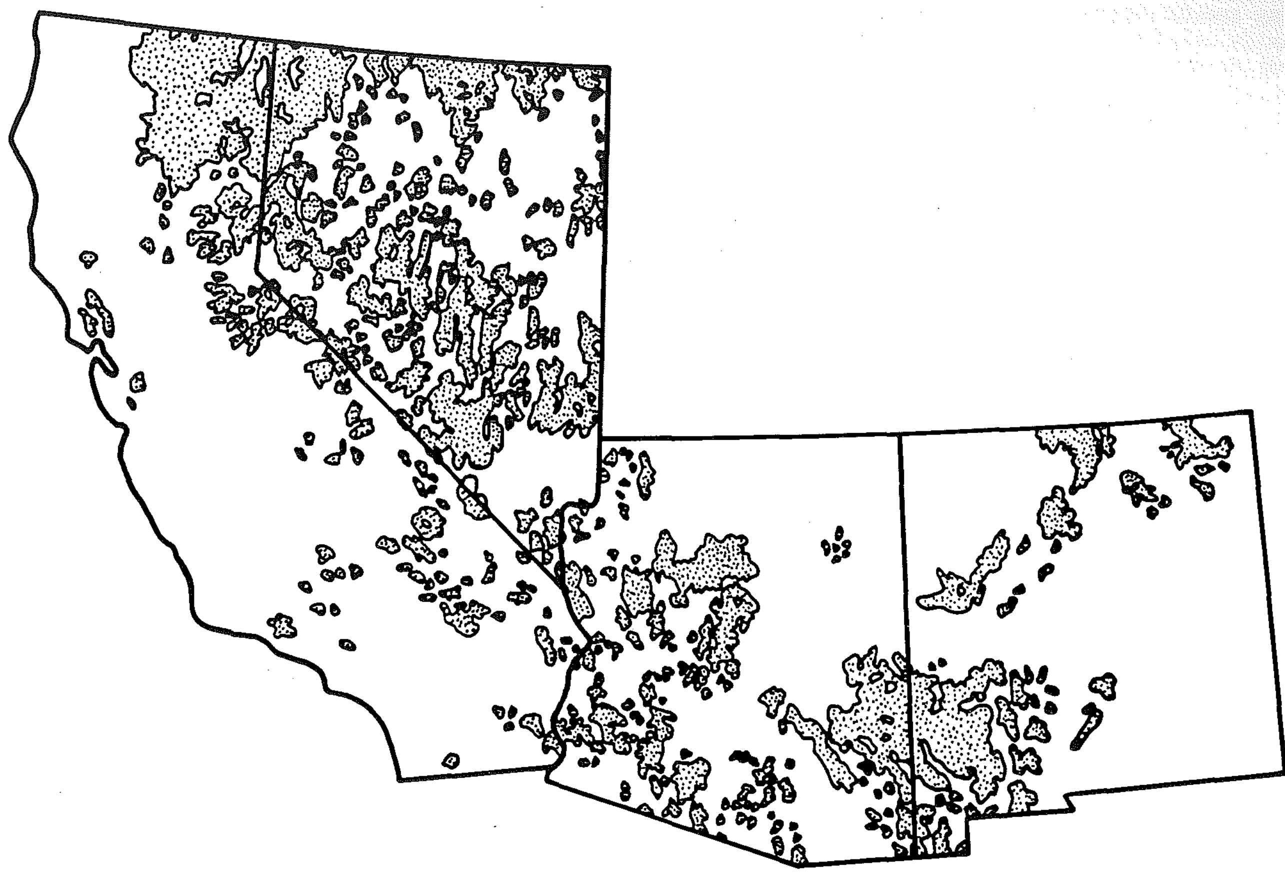

Figure 1. Distribution of Tertiary and Quaternary volcanic rocks in the Southwest.

color. It is generally rhyolitic in composition with a silica content near 70 percent. Vesicles are very abundant, usually small, and may be either spherical or elongated depending on cooling and consolidation history. Siliceous magmas have a higher viscosity than mafic magmas and solidify quickly, resulting in smaller, more abundant vesicles than in basaltic volcanic cinder. In general, in excess of 95 percent of the pumice particles are glass, with crystal phenocrysts making up the balance, most commonly quartz, K-feldspar, and biotite.

Most pumice deposits are formed as tuffaceous units, as shown in Figure 2, spatially associated with nearby siliceous volcanic centers. The pumice may be blown many miles by an explosive eruption with coarser particles settling closer to the source, while fines, carried by the wind, may sometimes travel vast distances. Exploitable pumiceous tuff units can attain thicknesses measurable in hundreds of feet and cover hundreds of square miles in some parts of the world. Particle size distribution within most pumiceous tuff units range from ash size to a few inches but occasionally attain dimensions up to two feet.

Physical characteristics of pumice units that make them desirable for use as lightweight aggregate vary greatly from deposit to deposit and within individual deposits. Younger units are generally less consolidated and weathered, and therefore yield easily mined and processed, stronger, individual clasts. Particle size distribution is impor-

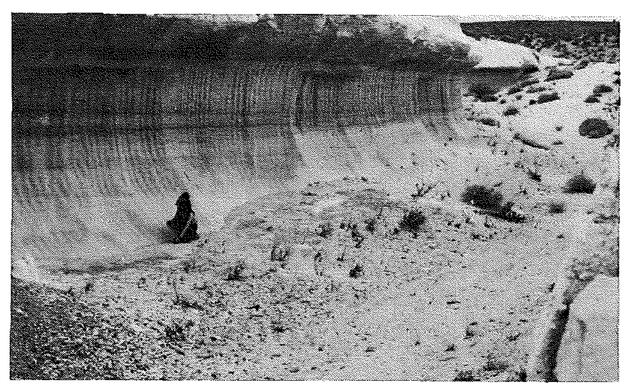

Figure 2. *A pumiceous tuff unit in the Bishop Tuff, Mono County, California, that was mined in the early 1950's.*

tant because a deposit with excessive fines may result in excess waste. Processing of the material is simple, consisting of screening, and crushing of the oversize.

The principal use of pumice in the construction industry is for weight reduction in the manufacture of concrete masonry units. In this application, the pumice is confined to course aggregate fractions in the size range from 1/2-inch to a No.8 sieve size. The finer fraction material, sand, is generally not pumice and is usually composed of aggregate of ordinary weight. Coarse pumice, in sizes up to approximately 3/4-inch, is sometimes utilized in portland cement concrete, but, for the most part, not as the only coarse aggregate ingredient. Pumice is the lightest of the natural lightweight aggregates. It is, however, also the weakest. It is, therefore, usually present as only a fraction of the total aggregate required in a concrete mix in order that the end product will have sufficient strength.

Volcanic Cinder

Volcanic cinder, sometimes referred to as scoria, lapilli, or just cinder, is a coarsely vesicular mafic volcanic material of sizes generally less that a few inches across. It is basaltic in composition and vitric to aphanitic in texture. Vesicles are abundant and may also be either spherical or elongated, as in pumice. In general, the vesicles in cinder are larger than those in pumice, sometimes attaining dimensions of an inch or more. Like pumice, cinder is a result of rapid cooling of magma containing abundant volatiles, but unlike the siliceous magma that gives rise to pumice, the mafic magma is less viscous. Magma of basaltic composition flows readily and acts more like a typical liquid. Cinder is black to red in color, sometimes acquiring a purplish appearance. Particle size of clasts in a typical cinder deposit ranges from ash size to volcanic bombs, occasionally attaining dimensions of several feet in length.

Volcanic cinder is a pyroclastic rock, erupting from a volcanic vent and, most commonly, forming a cinder cone. Cinder cones range in size from tens of feet to over a thousand feet in height. Occasionally, cinder is found as part of composite cones where it is interlayered with less volatile basic flows of magma. Well-formed cones are steep sided and usually reach the angle of repose of the cinder particles. The color of the cinder is related to the oxidation state of the iron in the parent magma and both red and black are often found in the same cone. Cinder cones may be found in isolated occurrences or as part of large volcanic fields, such as the hundreds of cones found in the vicinity of the San Francisco volcanic field in northern Arizona (see Figure 3).

Cinder cones of various ages and degrees of weathering can be found in several locations in the Southwest. Younger cinder deposits, which are readily distinguishable as cones, generally are the better material for use as lightweight aggregate. Older, weathered deposits, may not be easily identifiable as cones and often contain punky material and clays. Processing of cinder for use as lightweight aggregate is simple, consisting primarily of screening and crushing of the oversize.

Millions of tons of volcanic cinders are mined each year and utilized in the construction industry. Most of the production is directed to road base material or other types of construction where weight is not a primary factor. Cinder produced strictly for its lightweight properties is used principally in concrete masonry units. Much of the block manufactured in the Southwest includes cinder as an ingredient...thus the term "cinder block" is truly applicable. It is used in lightweight portland cement concrete but to a lesser extent. Cinder is a much stronger aggregate than pumice and, as in pumice, the finer size fractions are not generally used because as cinder becomes finer it is less porous, hence the density increases. Also, cinder fines tend to discolor concrete and concrete masonry units, a problem in aesthetics.

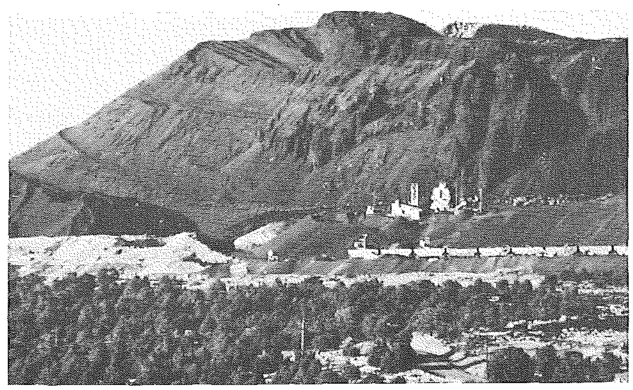

Figure 3. *One of the largest volcanic cinder operations in Arizona produces from a Quaternary cone near Flagstaff.*

Pumiceous Rhyolite

The third type of NLA used in the Southwest is pumiceous rhyolite. This material is not as well known nor as widely distributed as pumice or volcanic cinder and is a more recent addition to natural rocks being utilized as lightweight aggregate. Pumiceous rhyolite, chemically, is nearly identical to pumice in that it is the product of a siliceous melt with a silica content in the 70 percent range. Pumiceous rhyolite is also composed of in excess of 90 percent glass, is similar in color to pumice, but is much less vesicular.

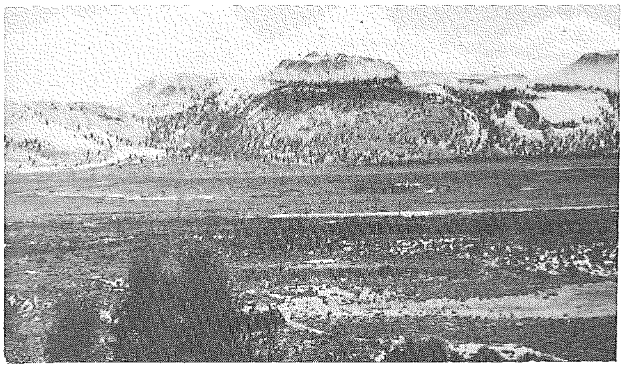

Figure 4. *The Mono Craters near Mono Lake are recent rhyolitic domes that contain pumiceous rhyolite.*

Vesicles are much smaller than those of pumice but usually are well distributed throughout the rock. Phenocrysts include quartz, feldspars and micas. Pumiceous rhyolite deposits are found as (1) domes, and (2) tuff breccia units.

Domes, especially those that are young in age such as at Mono Craters (Figure 4), are often spatially associated with what would be considered a classic pumiceous tuff unit. A typical young dome, as shown in Figure 5, is composed of denser rhyolite in the interior with progressive envelopes of less dense vesicular material surrounding it. Pumice often mantles the surrounding countryside. As with pumice, the melt producing the pumiceous rhyolite was highly viscous. Rhyolite domes containing pumiceous rhyolite may also contain perlite, obsidian or banded rhyolite flows. Here again, as in the pumice and volcanic cinder deposits, the amount of vesiculation and its distribution is governed by the amount of volatiles in the parent melt and its distribution in the eruptive sequence.

Tuff-breccia units consist of individual pieces up to two feet across set in a matrix of ash. Generally, there are no pumiceous tuff units associated with these deposits. The pumiceous rhyolite tuff-breccia units evidently were more volatile than those of domes, but the individual clasts are very similar in that they exhibit very small vesicles. The breccia deposits display a bedded aspect in that they maintain consistent thicknesses with definite upper and lower boundaries. They are often associated with rhyolite or rhyolite glass flows and ordinary siliceous tuff units. The spatial extent of the pumiceous rhyolite breccia is more limited than the associated tuffs and flows, which probably indicates closer proximity to a parent volcanic vent.

Pumiceous rhyolite is being utilized in both portland cement concrete and concrete masonry units and in all size fractions, both coarse and fine. The fine fraction, unlike cinder, is similar in density to the coarse because the tiny vesicles are evenly distributed. In addition, both the coarse and fine fractions are relatively strong. Even though pumiceous rhyolite may be heavier than either pumice or cinder, the end product may be similar in weight because the pumiceous rhyolite fines can be used.

DISTRIBUTION OF DEPOSITS

Figures 6 through 8 show the general distribution of known deposits of each of the NLA described. As previously mentioned, young volcanics are found only in the western portion of the United States where there are large volcanic fields or individual volcanic centers containing suitable glassy, low-density rocks.

Although production estimates are given below for each of the three aggregate types, they should be used with caution. Wide fluctuations in production occur in relation to the economic health of the construction industry. In addition, for various reasons, production data from federal and state sources often conflict. Available information does not always reflect the end product application - is the material being used as a lightweight

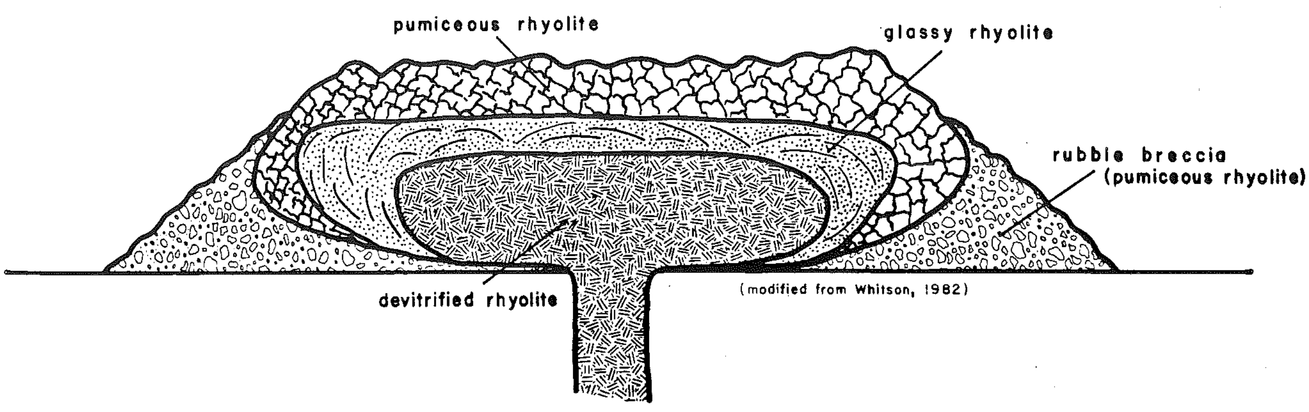

Figure 5. *Schematic cross section of a typical Quaternary rhyolite dome.*

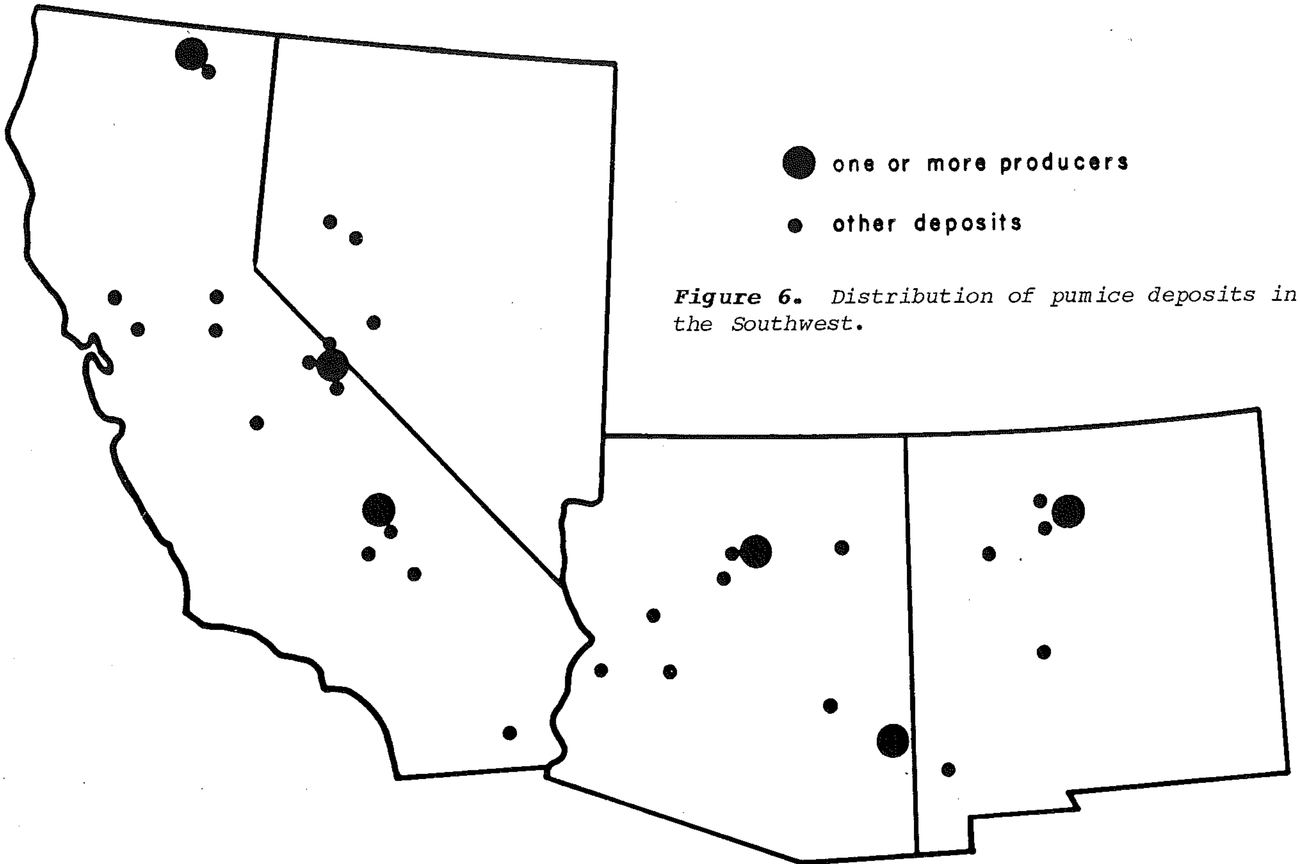

Figure 6. *Distribution of pumice deposits in the Southwest.*

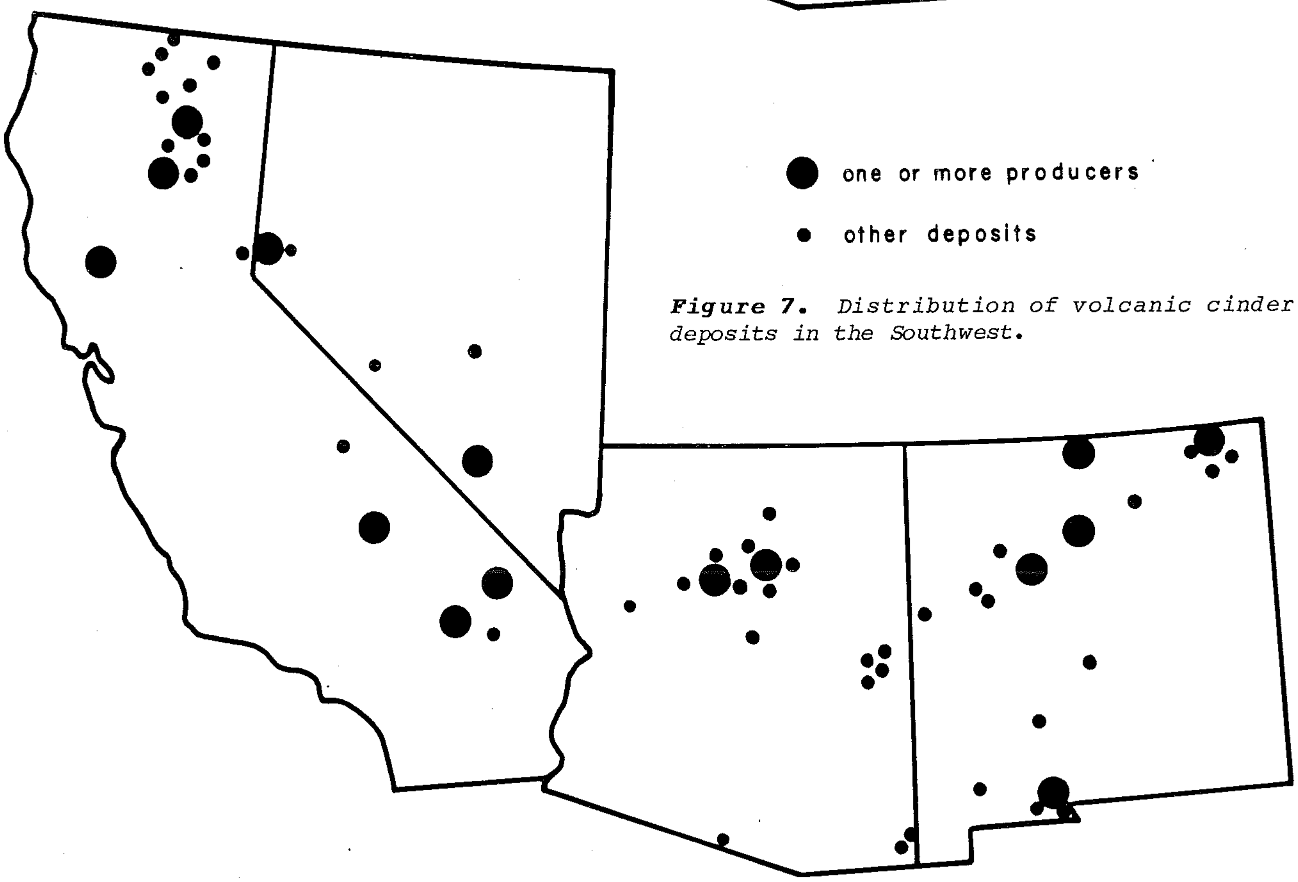

Figure 7. *Distribution of volcanic cinder deposits in the Southwest.*

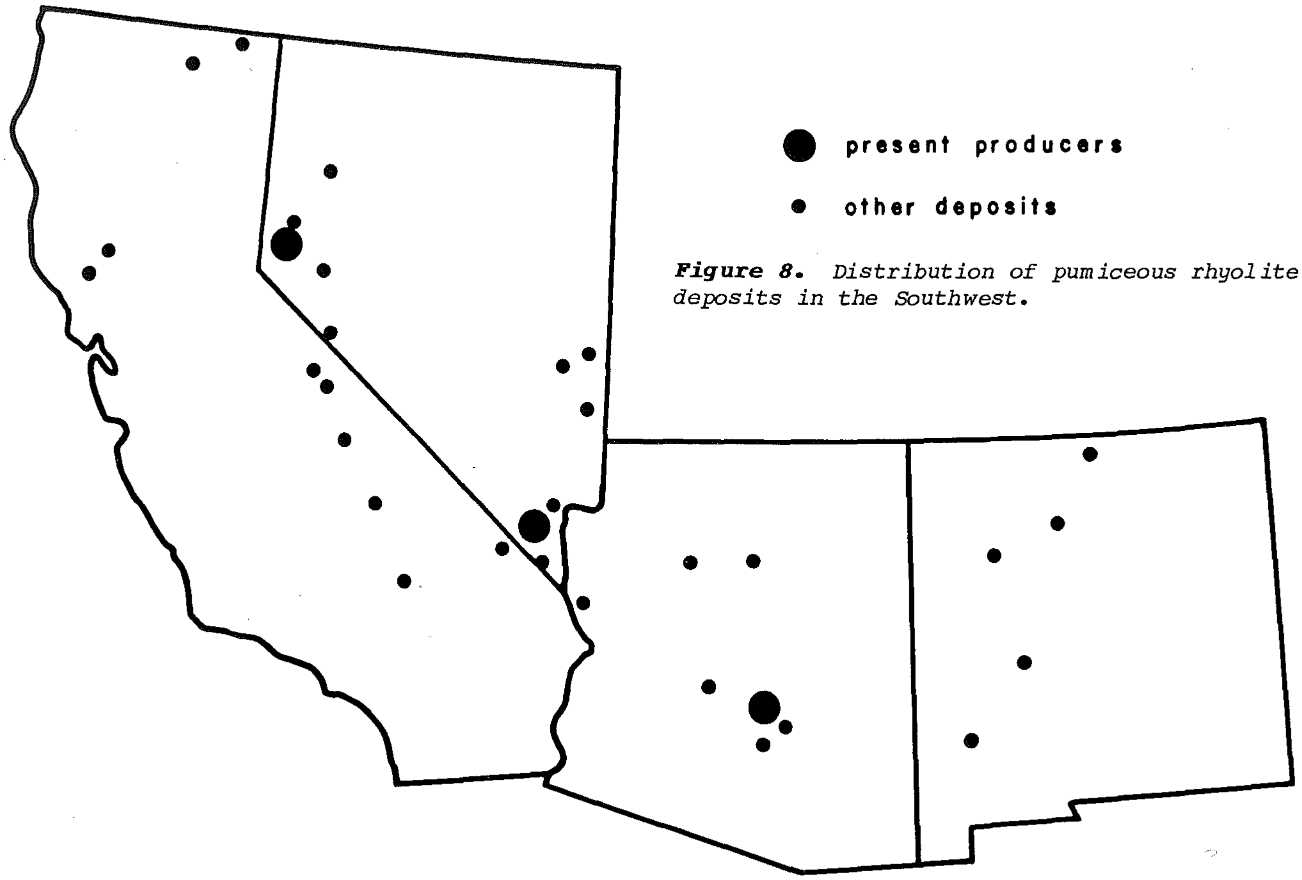

Figure 8. Distribution of pumiceous rhyolite deposits in the Southwest.

aggregate? An example is volcanic cinder; the U.S. Bureau of Mines does not group this commodity separately. In addition, the majority of the cinder mined in the Southwest is not utilized as a lightweight aggregate, but rather as a substitute for sand and gravel or crushed rock in other applications.

Pumice

The distribution of pumice deposits in the Southwest is shown in Figure 6. According to statistics from the U.S. Bureau of Mines, about 500,000 tons of pumice per year is produced in the United States. The states of New Mexico and California in the Southwest are two of the four major pumice producing states in the country. In 1982 New Mexico production was approximately 100,000 tons, while California's production was approximately 60,000. Production in Arizona is less than 30,000 tons, and Nevada currently has no pumice production.

The most comprehensive description of pumice in California is by Chesterman (1956). Those deposits having a history of utilization include both subaerial and subaqueous deposits, ranging in size from a few thousand tons to many hundreds of thousands of tons. The southern Coso Range area, at the southern end of Owens Valley in Inyo County, is the largest current producer in the state, furnishing lightweight aggregate to the southern California market. Chesterman describes these deposits as being tuffs of both subaqueous and nuee ardente origin. In northern California in the Glass Mountain area in eastern Siskiyou County, pumice from a recent, loosely consolidated tuff is produced and shipped as far south as the San Francisco Bay area. Minor amounts of pumice are produced periodically from other localities in California, including the Bishop and Mono Lake region, and the front ranges of the Sierras near Fresno. The majority of pumice production in California occurred prior to the late 1950's. Counties with considerable past production include Siskiyou, Napa, Mono, Inyo, and Kern.

The principal pumice producers in New Mexico are mining material from tuffaceous deposits located near Santa Fe on the eastern and southern flanks of a caldera that forms the Jemez Mountains. Here the deposits are the lower member of the Pleistocene Bandelier Tuff and may attain thicknesses as great as 70 feet with little or no overburden. Past production has also taken place from tuffaceous units near Grants, west of Albuquerque. Minor pumiceous rhyolite are often associated with the pumice deposits of Figure 6. Pumiceous rhyolites can be found in all the southwestern states, but the only production currently is in Nevada and Arizona.

Nevada, the largest producer, has three active pumiceous rhyolite deposits. Near Reno, in northern Nevada, two producers are mining from rholitic domes. The Reno area is by far the largest utilizer of pumiceous rhyolites, the value of these deposits having been recognized over 25 years ago. Some of this material is shipped into nearby Sacramento, California. A third producer in Nevada is located just south of Las Vegas, where a tuff breccia unit is being mined. In both Las Vegas and Reno, the material is used in both concrete masonry units and portland cement concrete.

Arizona has one producing pumiceous rhyolite deposit, a tuff breccia unit approximately 60 miles east of Phoenix. Here the material is primarily used as a lightweight aggregate in concrete masonry units, but has been occasionally utilized in portland cement concrete as well.

New Mexico contains several young rhyolitic domes containing pumiceous rhyolite that have potential for use as a lightweight aggregate. Some effort has been made to put a deposit located near a major metropolitan area into production, but conflicting land usage precluded this possibility.

California contains abundant pumiceous rhyolite, both in domes and as tuff breccia units. No significant production has taken place. There was an effort recently, however, to put a deposit located near a major metropolitan area into production, but conflicting land usage again precluded this possibility.

Conclusion

Natural lightweight volcanic aggregates are attaining greater application in the Southwest primarily due to their recognized economic benefits to the construction industry, the rise in energy costs over the last decade, and the identification of new natural lightweight resources.

The geology and physical characteristics of the NLA discussed here impart certain unique properties that make them suitable for use in lightweight applications of portland cement concrete and concrete masonry units. Pumice is the lightest of the three natural lightweights, is very porous and, correspondingly, has the lowest physical strength. Volcanic cinder is intermediate in weight, highly porous, but generally, has good strength. Pumiceous rhyolite is heavier than pumice, and stronger, and, as a rule, heavier than cinder but has a lower absorption. These basic characteristics of the three materials, as well as others not discussed, govern the ultimate proportions and usage of the aggregates in the end product, but all are employed in the manufacture of lightweight construction materials.

The outlook for increased usage of these natural lightweights should continue to improve as population and the construction industries of the Southwest expand. The opportunity exists for some previously exploited resources to regain a market and for hertofore unrecognized resources, especially the pumiceous rhyolites, to be developed. Pumiceous rhyolites may have the greatest potential for increased utilization as a lightweight aggregate as they have been the least recognized for this purpose.

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occurrences of pumice have been reported elsewhere in the state. Pumice is currently being produced from a deposit near Flagstaff in Northern Arizona where extensive pumiceous tuff units are a part of the San Francisco volcanic field. Production is shipped primarily to the Phoenix area. Minor production also comes from a deposit approximately 25 miles east of Safford and is used locally.

Nevada currently has no pumice production. In the past, minor production came from two tuffaceous deposits near Fallon, in Churchill County, in the west central part of the state. Pumice deposits in Nevada are limited to the western portion of the state and tend to be very limited in aerial extent and generally of low quality. This is in contrast to the other three Southwestern states that have large, high quality pumice reserves.

Volcanic Cinders

Volcanic cinder is produced in all four of the states in the Southwest as shown in Figure 7. Current production far exceeds that of pumice because cinder is utilized in more applications and is more abundant. Volcanic cinder in many localities is used not only as a lightweight aggregate, but also as roadbase and fill material where other traditional sources of construction materials, such as sand and gravel, are lacking. Cinder occurs in great quantities in all four of the states in the Southwest. Some of the larger volcanic fields contain hundreds of cinder cones while isolated cones are also found as part of smaller, widely-distributed mafic eruptions.

Total production in the western United States is probably on the order of many millions of tons. This is difficult to pinpoint, however, because U.S. Bureau of Mines statistics often includes cinder production, because of its use, with crushed stone. California and Arizona are the largest producers of volcanic cinders for all applications. Total production in Arizona of cinder is probably in excess of 500,000 tons per year. California ranks next in production for lightweight applications at slightly under the same tonnage, followed by New Mexico, with approximately 150,000 tons, and lastly, Nevada, with less than 50,000 tons. The number of active operations varies from 15 in California to only two in Nevada.

The principal source of supply of volcanic cinder in Arizona is from the San Francisco volcanic field stretching from near Flagstaff, west to Ash Fork. At least seven deposits are active in this area with most of the material being produced for lightweight aggregate applications and shipped south to the Phoenix area for use in lightweight concrete masonry units. The San Francisco volcanic field contains literally hundreds of extrusive centers, many of which are volcanic cinder cones.

Smaller amounts of cinder have been produced from other mafic volcanic fields in Arizona including the White Mountains near the eastern border, and the San Bernardino Valley in the extreme southeast corner of the state. Nearly all production of volcanic cinder in Arizona has been from Quaternary cinder cones. Further information concerning volcanic cinder in Arizona is described by Keith (1969); see Welty and Spencer - this volume.

California volcanic cinder production comes from deposits in both the northern and southern parts of the state. Isolated cinder cones at Little Lake in southern Inyo County, and at Pisgah Crater in the Mojave Desert furnish lightweight aggregate for the Southern California market. In Northern California, cinder comes from the extensive volcanic field stretching from near Lassen Volcanic National Park north to the Oregon border, and from isolated cinder cones in the Clear Lake area in Lake County, north of San Francisco.

The extensive volcanic field from Lassen north contains considerable reserves of cinder in at least a hundred cones. In southern California additional isolated cinder cones can be found from Mono Lake south into Owens Valley and at Amboy in the central Mojave Desert. A small mafic volcanic field at Cima, close to the Nevada border, has several cinder cones with some material being shipped to Las Vegas for use as lightweight aggregate in concrete masonry units. Chesterman (1956) describes in detail many of the cinder deposits of California.

Volcanic cinder in New Mexico has been most recently discussed by Osburn (1982). The majority of the production comes from several cinder cones in an extensive volcanic field in the northeast corner of the state in Union County. Here the material is mined and shipped by rail to several nearby states for use in lightweight aggregate applications. These are the most easterly exploitable cinder deposits in the country. Other lightweight aggregates are mined near Santa Fe, Albuquerque, and northwest of El Paso, Texas. All production comes from Quaternary cinder cones.

The smallest producer of volcanic cinder in the Southwest is Nevada. Only two deposits, both Quaternary, are currently in production; one being near Lathrop Wells in Nye County in southern Nevada, which furnishes lightweight aggregate for a concrete block plant in Las Vegas, and the other near Carson City in northern Nevada, which occasionally furnishes material for use in lightweight portland cement concrete. Nevada has fewer cinder deposits than the other southwestern states, and these are found as isolated cones, not large volcanic fields.

Pumiceous Rhyolite

The distribution of pumiceous rhyolite is shown in Figure 8. Rhyolitic domes containing

Acquisition of Federally Owned Industrial Minerals

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ABSTRACT

Federally owned mineral deposits generally fall into one of three categories: (1) minerals locatable under the General Mining Law of 1872; (2) minerals leasable under the Mineral Leasing Act of 1920; and (3) minerals salable under the Materials Act of 1947. Unlike valuable deposits of gold, silver, copper, iron, lead, etc., which may be locatable, industrial minerals are acquired through a variety of methods depending on use, composition, and date of acquisition. Table 1 may be used to establish the method of acquisition for most industrial minerals.

REVIEW OF THE FEDERAL MINING LAWS

For almost 200 years Congress has wrestled with the problem of mineral disposal. As early as March 3, 1807 (2 Stat. 448), a law was passed that authorized leasing of lead mines. Most mineral lands were disposed of by a leasing arrangement until the Acts of July 11, 1846 (9 Stat. 37) and March 1, 1847 (9 Stat. 146) authorized the sale of mineral lands.

In 1848 gold deposits were discovered in California. This stimulated tremendous controversies about how to dispose of Federal minerals. Most of the controversy was between the Federal government and the State of California. Both sides proposed several schemes, including numerous proposals to tax the mines, lease mineral lands, and sell mining permits. California miners preferred that the state rather than the Federal government administer the disposal of minerals. All through this period of controversy, rules and regulations proposed and established by the miners allowed a reasonable amount of stability in the mining camps. These ordinances established a location system based on specifying claim size, location procedure, and work required to hold a claim.

The Act of July 26, 1866 (14 Stat. 251) was based on the rules and regulations in common use by the miners. Not only did this law establish a single set of mining requirements, but it also provided a means for the miners to obtain legal title to a mining claim upon expenditure of at least $1,000 per claim. The act declared all mineral lands owned by the public open to exploration and location.

Table 1. *Methods of acquisition of most federally owned industrial minerals.*

I. LOCATABLE MINERALS (30 USC 21)

A. All "valuable mineral deposits" not excluded below.
B. See V. B.
C. Examples:

Alunite, Asbestos, Barium minerals, Bauxitic raw minerals, Chromite, Diamonds, Diatomite, Exceptional clay, Feldspars, Fluorspar, Glauconite, Graphite, Gypsum and anhydrite, Kyanite and related minerals, Lithium raw materials, Magnesite and related minerals, Manganese, Mica, Nepheline Syenite, Olivine, Pyrophyllite, Rare Earths and Thorium, Silica and Silicon, Staurolite, Sulfur, Talc, Titanium minerals, Vermiculite, Wollastonite, Zeolites, (depending on chemistry, some are leasable)

II. MINERALS NEVER LOCATABLE

A. Widespread minerals of low unit value and used for ordinary purposes.
B. See V. A. 2.
C. Examples: Ordinary clay; Peat; Material used for fill, levees, and ballast

III. LEASABLE MINERALS (30 USC 181 ET SEQ.)

A. Before leasing act, most (except coal) were probably locatable.
B. After leasing act, available only through lease, unless valid existing rights.
C. Examples: Oil, gas, coal, bituminous materials, borates, phosphate, potash, sodium, geothermal resources

IV. SALABLE MINERALS (30 USC 601)
Sand, stone, gravel, common clay

A. Before Materials Act of July 31, 1947, most deposits were unavailable under any system; after Materials Act, they could be purchased.
B. Materials locatable until July 23, 1955; then salable, unless valid existing rights (See V. A. 1.).

V. COMMON VARIETIES ACT MINERALS (30 USC 611)
Sand, stone, gravel, pumice, pumicite, or cinders

A. Common Varieties (now salable):
   1. Locatable until July 23, 1955 (see IV. B.)
   2. Never locatable (see IV. A.)
B. Uncommon Varieties - to qualify, a mineral must satisfy one of the following:
   1. Special use (because of intrinsic property giving distinct and special value).
   2. Higher price in the market (because of intrinsic property giving distinct and special value).
   3. Lower production cost, so higher profit (because of intrinsic property giving distinct and special value).

Only one location up to 200 feet in length was allowed along each lode or vein. Payment for patent of lode claims was $2.50 per acre.

The Act of July 9, 1870 (16 Stat. 217) amended the Act of July 26, 1866 to include placer locations. It limited placer locations to a maximum of 160 acres and required that such locations conform to legal subdivisions on surveyed lands. Valid placer claims could be patented upon payment of $2.50 per acre.

The General Mining Law of May 10, 1872, replaced much of the 1866 and 1870 mining acts. Although the 1872 mining law has been amended many times, it still remains surprisingly intact after more than 100 years.

The 1872 law authorized placer- and lode-mining claims, mill sites, and tunnel sites of specific dimensions. At least $100 worth of work was annually required on each claim to maintain a possessory title. Placer claims, lode claims, and mill sites could be patented upon expenditure of $500 worth of work, provided the discovery requirements were met.

The Mineral Leasing Act of February 25, 1920 (41 Stat. 437) provided that deposits of coal, phosphate, oil, oil shale, gas, and sodium could be acquired only through competitive and noncompetitive leasing systems. The Act of April 17, 1926 (44 Stat. 301) made sulphur in public lands in New Mexico and Louisiana subject to the 1920 Leasing Act. The Act of February 7, 1927 (44 Stat. 1057) authorized that chlorides, sulphates, carbonates, borates, silicates, or nitrates of potash be included as leasable minerals. The Materials Act of July 31, 1947 (61 Stat. 681) authorized disposal of sand, stone, gravel, and common clay through a contract of sale.

Minerals Locatable Under the Mining Laws

Federal mining laws (30 USC Sec. 22) state the following:

> Except as otherwise provided, all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, shall be free and open to exploration and purchase....

If valuable mineral deposits are locatable, what then is a "valuable mineral deposit"? The Federal regulations 43 CFR 3812.1 define a locatable mineral in this way:

> Whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws.

Although this definition of a locatable mineral is somewhat vague, it could undoubtedly be applied to almost any mineral that has sufficient value to be extracted and marketed at a profit. Because of this value requirement, there is no such thing as a list of locatable minerals. For example, some deposits of gold, uranium, and gemstones are valuable, whereas other deposits are not. Whether or not a particular mineral deposit is locatable depends, therefore, on such value-influencing factors as quality, quantity, minability, demand, marketability, etc.

Minerals Not Locatable

Rather than attempting to establish which minerals are locatable, it may be more practical to discuss which minerals are definitely not locatable. The number of locatable minerals authorized by the 1872 Mining Law has been substantially reduced by several subsequent Federal laws. The Mineral Leasing Act of 1920, as amended, authorized that the following deposits may be acquired only through a mineral-leasing system: oil, gas, coal, potassium, sodium, phosphate, oil shale, native asphalt, solid and semisolid bitumen and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined or quarried, and sulphur deposits in Louisiana and New Mexico. The Materials Act of July 31, 1947 (61 Stat. 681), amended by the Act of July 23, 1955 (69 Stat. 367), excluded common varieties of sand, stone, gravel, pumice, pumicite, cinders, and clay; however, uncommon varieties of sand, stone, gravel, pumice, pumicite, cinders, and exceptional clay are locatable. The Act of September 28, 1962 (76 Stat. 652) removed petrified wood from the locatable-mineral category.

Before the Materials Act of 1947 and the Act of July 23, 1955 were enacted, many mineral materials were never locatable even though they could be marketed at a profit. In fact, the Materials Act of 1947 was enacted to provide a means to dispose of them. Material in the category includes ordinary deposits of clay, limestone, fill material, etc. Nonlocatable minerals generally have a normal quality and a value for ordinary uses. In _Holman et al. v. State of Utah_, 41 LD 314 (1912), the question of whether clay was a locatable mineral was considered:

> It is not the understanding of the Department that Congress has intended that lands shall be withdrawn or reserved from general disposition, or that title thereto may be acquired under the mining laws, merely because of the occurrence of clay or limestone in such land, even though some use may be made commercially of such materials. There are vast deposits of each of these materials underlying great portions of the arable land of this country....

Other Federal court and departmental decisions have found that such minerals as decomposed rhyolite, windblown sand, peat moss, and sand and gravel, if suitable only as fill, soil conditioners, or other low-value purposes, were never locatable.

Lands Open to Exploration

The mining law states that "except as otherwise provided, all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, shall be free and open to exploration and purchase, by claims are located on unsurveyed lands. If the claims conform to such legal subdivisions, no further survey or plat is required for patent. On unsurveyed land and in certain situations, placer claims may be located by metes and bounds.

No location for a placer claim may exceed 20 acres for each individual who participates. An association of two locators, however, may locate 40 acres; three may locate 60 acres; and so on. The maximum area that may be embraced by a single placer claim is 160 acres and such a claim must be located by an association of at least eight persons. Corporations are limited to 20-acre claims. A 20-acre placer claim might be described as being in N 1/2 NE 1/4 NW 1/4 sec. 5, T. 5 N., R. 3 W., Boise Meridian.

Uncommon varieties of building stone may be located with placer-type claims pursuant to the Act of August 4, 1892 (27 Stat. 348; 30 USC Sec. 161). The law requires that building-stone placers may be located only on lands "that are chiefly valuable for building stone." The Act of July 23, 1955 (69 Stat. 367; 30 USC Sec. 611) withdrew common varieties of building stone from entry under the mining laws.

Lode Versus Placer

Many mineral deposits do not fit easily into the category of either a lode or placer deposit. As stated previously, the only statutory guidance concerning the definition of a lode claim is in section 2 of the 1872 mining law:

> "...mining claims upon veins or lodes of quartz or other rock in place bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits...."

The statutory definition of a placer claim (30 USC Sec. 35) includes "all forms of deposit, excepting veins of quartz or other rock in place." The key definition is that given for a lode-mining claim. Many court decisions, in considering the definition of a lode, generally have held that the shape or nature of the deposit is more significant than its origin. This is just as well because the origin of a particular deposit may be difficult to ascertain, especially where associated with metamorphic rocks.

There are several advantages that a placer location offers over a lode location: (1) only one discovery of mineral is required to support a placer location whether it be 20 acres or 160 acres; however, each 10-acre subdivision must be mineral in character; (2) $100 worth of work must be expended on a placer claim whether it be 20 acres or 160 acres; and (3) if the claim is to be located on surveyed lands, it can be described by legal subdivision. A placer location, therefore, is more easily and cheaply effected than a lode location and more secure from rival claimants.

Mill Sites

The Federal requirements for mill sites are set forth in 30 USC Sec. 42 and 43 CFR 3844. Mill-site locations shall not exceed 5 acres in size. The land under location must be nonmineral and noncontiguous to the vein or lode. Although a mill site may adjoin the side lines of a lode-mining claim, it is unlikely that lands adjoining the end lines would be either nonmineral or noncontiguous to the vein.

The Federal law authorizes three general categories of mill sites:

1. A mill may be located if needed by the owner of a lode-mining claim for mining and milling purposes. Such a mill site may be patented with the associated lode claim and is subject to the same survey, notice requirements, and charges that apply to lode claims.
2. The Act of March 18, 1960 authorized the location of a mill site if needed by the owner of a placer claim for mining, milling, processing, beneficiation, or other operations in connection with such a claim. Such a mill site may be patented with the associated placer claim and is subject to the same survey, notice requirements, and charges that apply to placer claims.
3. A mill site may be located to establish and maintain a custom or independent quartz mill or reduction works. The owner of such a mill need not own a mine in connection with the mill. A custom mill may qualify for patent in the same manner as mill sites located in connection with lode claims.

There is no information in the Federal law or regulations concerning how a mill site or, how many, may be located. It may be presumed that a mill site may be located by legal subdivision, if associated with a placer claim that is located by legal subdivision; and conversely, a mill site may be located by metes and bounds, if associated with a lode claim.

Tunnel Sites

Tunnel locations are made by erecting a substantial post or monument at the tunnel entrance. Stakes or monuments should be placed along the line of the tunnel at appropriate intervals up to 3,000 feet from the entrance. The owner of a mining tunnel has the possessory right to 1,500 feet of any blind lodes cut, discovered, or intersected by the tunnel. This gives the locator of the tunnel the exclusive right to prospect an area 3,000 feet by 3,000 feet while work on the tunnel continues. Claims staked by other citizens of the United States and those who have declared their intention to become such." (Act of May 10, 1872; 17 Stat. 91; 30 USC 22.)

Public lands belonging to the United States are open to entry under the General Mining Laws unless particular lands have been withdrawn by congressional authority or by an executive authority either expressed or implied. [Lockhart v. Johnson, 181 US 516 (1901).]

Mining claims may be located on unreserved, unappropriated lands administered by the Bureau of Land Management (BLM), U.S. Department of the Interior and or unreserved, unappropriated public-domain lands in national forests administered by the Forest Service, U.S. Department of Agriculture. Mining locations may be made in the States of Alaska, Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. [43 CFR 3811.2-1(a).]

Lands patented under the Stockraising Homestead Law or other land-disposal laws that reserved locatable minerals to the United States are subject to mineral location. The mineral reservation in the patent separates the land into a surface estate and a subsurface mineral estate. The mineral estate is subject to location under the general mining laws in the same manner as are vacant, unappropriated public lands. The surface owner, however, is entitled to compensation for any damages resulting from exploration or mining.

Lands Closed to Location

The national parks and national monuments are closed to mining location; however, valid mining claims that were in effect when a national park or monument was established are entitled to certain grandfather rights. Indian reservations, military reservations, most reclamation projects, Federal wildlife refuges, and land segregated under the Classification and Multiple Use Act are generally closed to mining location.

Numerous land withdrawals and land classifications have served to segregate the public lands from mineral location and entry. Before a mining claim is located, the public land records of the Bureau of Land Management should be examined to determine if the area of interest is available for mineral entry. A mineral location on lands segregated from mineral entry would not only be a waste of time and money, but would also be an unauthorized trespass.

Reserved Minerals Not Subject to Mining Law Without Specific Authority

It is well established that where locatable minerals are reserved in a Federal land patent or disposal, the reserved minerals are not open to location of mining claims. For example, reserved minerals in patents issued under the Recreation and Public Purposes Act (43 USC 869) are not open to mineral location. The only exception to this rule is where the statute authorizing the disposal specifically provides that the reserved minerals are subject to the mining laws, as does the Stock Raising Homestead Act of 1916. [City of Phoenix v. Reeves, 14 IBLA 315, 327-28 (1974).]

Types of Claims and Sites

The mining law authorizes four types of appropriations: lode claims, placer claims, mill sites, and tunnel sites. Each type has its own method of location and purpose.

Lode-Mining Claims

Lode-mining claims may be located upon discovery of a vein or lode "of quartz or other rock in place bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits" (30 USC Sec. 23). A lode claim may not exceed 1,500 feet in length along the course of the vein or lode, nor extend more than 300 feet at the surface along either of side of the middle of the vein. The dimensions of a lode-mining claim, therefore, must not exceed a parallelogram 1,500 feet in length by 600 feet in width. Federal law also requires that the end lines of each claim be parallel to each other.

Federal regulations (43 CFR 3841-5) specify that certain information must be contained in the location notice. The course and distance from the discovery shaft on the claim to some permanent, well-known object, such as stone monuments, blazed trees, confluence of streams, intersection of roads and prominent mountains, must be described as accurately as practicable. Survey monuments such as brass-cap section corners are excellent markers, especially because the Federal law (30 USC Sec. 23) requires that the location of the claims must be designated with reference to the lines of the public survey if such claims are on surveyed lands. It is not necessary, however, that the claims conform to the public survey. Post or stone monuments should be established at the corners of the claim to mark the claim boundaries.

Placer-Mining Claims

Placer claims may be located for "all forms of deposit, excepting veins of quartz or other rock in place" (30 USC Sec. 35). All placer-mining claims must conform as closely as practicable with the U. S. system of public-land surveys and the rectangular subdivisions of such surveys, even though the

Statutory Definition of Discovery

The Act of May 10, 1872 (30 USC 22) states that "... all valuable mineral deposits in lands belonging to the United States ... shall be free and open to exploration and purchase...."

Although the statutes do not prescribe a test for determining what constitutes a discovery of a valuable mineral deposit, the department (BLM) and the courts have established a test through almost a century of decisions. These decisions seem to assume that Congress intended that "valuable mineral deposits" be valuable in an economic sense or could be worked as a paying mine. A profitable mining operation has always been considered as the best evidence of the discovery of a valuable mineral deposit.

No Discovery If Deposit Warrants Additional Exploration

It is a common pitfall for a claimant or his expert witness to reveal at the hearing that the deposit is mineralized to the extent that it justifies additional exploration or prospecting to find a commercial deposit. The hearing officer considers this to be an admission by the claimant that there is no discovery, but simply evidence that one may exist. This does not meet the present court interpretation of discovery that requires that a valuable mineral deposit has been found and is ready for development and mining. With a discovery, no more prospecting or exploration work to find the deposit would be necessary.

Numerous recent departmental and court decisions have held that in order to qualify as a discovery it must be established that the mineral deposit can be mined and sold at a profit and the development and mining operations may proceed with reasonable confidence. If the deposit requires additional exploration to delineate the ore reserves and determine grade or quality before development may be confidently started, a discovery has not been made.

Paying-Mine Need To Be Demonstrated

Although a mining claimant may be required to demonstrate that he has what could be developed into a profitable mine under present economic conditions, it is not required that he demonstrate a paying mine as an accomplished fact. In Adams v. U.S., 318 F2d 861 (9th Cir. 1963) the Court stated:

> "Discovery of a valuable mineral deposit within the limits of each claim is essential but value, in the sense of proved ability to mine the deposit at a profit, need not be shown."

Undoubtedly though, the most convincing demonstration of a valid discovery would be a mine presently operating at a profit. In Barrows v. Hickel, 447 F2d 80, 82 (9th Cir. 1971) the Court said that "actual successful exploitation of a mining claim is not required to satisfy the 'prudent-man test'."

Loss of Discovery

Worked-out claims do not qualify as valid mining claims. Although a mining claim may have been valid in the past because of discovery of a valuable deposit of mineral on the claim, the claim will lose its validity if the mineral deposit ceases to be valuable because of the change in economic conditions, or the mineral deposit is depleted.

Discovery in Each Claim

In contest proceedings involving more than one claim, the test of discovery is applied to each claim individually, because "(a) discovery without the limits of the claim, no matter what its proximity, does not suffice." [Waskey v. Hammer, 223 US 85, 91 (1912)]. In order to be valid each claim in a claim group must have a discovery within its boundaries. Under certain circumstances, however, the government has taken a broad look at this requirement. For example, in the case of large, low-grade, prophyry-copper deposits that by necessity require hundreds of claims to cover the mineralized area, it is obvious that any one claim could not stand by itself as a paying mine. The entire deposit must be available in order to be economically feasible. In acknowledging this fact, the government has issued mining patents on numerous such claims.

Validity at Date of Withdrawal and Date of Hearing

When land is closed to location under the mining laws subsequent to the location of a mining claim, the claim cannot be recognized as valid unless all requirements of the mining laws, including discovery of a valuable mineral deposit, were met at the time of the withdrawal and at the time of the hearing. [U.S. v. Netherlin, 33 IBLA 86 (1977).] Where land occupied by a mining claim has been withdrawn from operation of the mining laws, the validity of the claim must be tested by the value of the mineral deposit as of both the date of the withdrawal, and the hearing. [U.S. v. Chappell, 42 IBLA 74 (1979).] Even though there may have been a discovery at the time of the withdrawal or some other time in the past, a mining claim cannot be considered valid unless the claim is at present supported by a discovery. A loss of discovery, either through exhaustion of minerals, changes in economic conditions, or other circumstances, results in loss of the location. [U.S. v. Wichner, 35 IBLA 240 (1978).]

parties after the tunnel is started for lodes that are not apparent at the surface but are within the area claimed by the tunnel locator are invalid. The miner is entitled to locate lode claims to cover the veins intersected by the tunnel; however, if work on the tunnel ceases for 6 months, the tunnel locator abandons all rights to undiscovered veins on the line of the tunnel.

A notice of location must be posted on the monument at the tunnel entrance and filed in the county recorder's office of the county in which the tunnel is located. The notice of location should include the following information: (1) names of the locators; (2) actual or proposed direction of the tunnel, including tunnel height and width, and (3) distance from the entrance to some established survey monument or well-known permanent object.

Location Procedure

Before locating a claim, one should verify that the lands of interest are open to mineral location by examining the land-status maps and records at the Bureau of Land Management. Unpatented claims are recorded in the county recorder's office of the county in which the claim is located. There are four basic steps to location procedure: (1) discovery of a valuable mineral deposit; (2) marking the boundaries of a claim on the ground; (3) posting and recording the location notice with the county recorder and the BLM; and (4) discovery work if required by State law.

The appropriate State law should be consulted to determine monument specifications, manner of monumenting, information required in the location notice, and recording requirements.

Marking Claim Boundaries

Federal law requires that "the location must be distinctly marked on the ground so that its boundaries can be readily traced" (30 USC Sec. 28). Each State generally has detailed statutory requirements for marking claim boundaries. Most States require that a monument of specific dimensions and materials be placed at each corner of the claim. Placer claims located by legal subdivision generally do not require corner monuments. Materials used for monuments include posts, blazed trees, and piled rocks; however, the most common monument by far is the 4-inch-square post.

It is very important to mark the claim boundaries clearly with durable monuments because the position of the monument on the ground will generally prevail over the recorded description. The more difficult it is to move or destroy a monument, the less likely the claim will be overstaked. It is preferable to overlap claims slightly rather than to omit desired land unintentionally.

The Location Notice

Most States have laws that provide detailed procedures for posting and recording. Individual State requirements should be checked frequently because State law is amended from time to time. Regardless of whether or not a particular State requires a location notice to be posted and recorded, it is prudent to do so to make one's interest in the claim a matter of public record.

Because monuments placed in the field are easily lost or destroyed, a copy of the location notice should be recorded in the county recorder's office of the county in which the claim is located as soon as possible, even though individual States may allow up to several months. In Alaska the recording office is under the District Magistrate.

Although the information that must be included on a location notice varies from State to State, the following are usually required: (1) date of location; (2) name of claim; (3) name of locator(s); (4) type of claim (placer or lode); (5) mineral or minerals claimed; (6) distance claimed along strike of vein from discovery monument to each end line; (7) direction of vein; (8) length and width of claim; (9) portion of section, township, and range and total acreage (for placer claims located by legal subdivision), and (10) give the distance and direction from discovery or corner monument to a fixed place such as a brass-cap section corner or to a well-known natural object or landmark such as a mountain, road intersection, or stream confluence.

It is extremely important that the recorded location notice has an accurate description of the claim location. Many claims have such a vague description that they could exist anywhere over a large area. A big problem in connection with such a claim is that it could be moved to overlap a subsequent discovery in the vicinity. Because such claims, often referred to as "floating claims", record an earlier location date, they could present a serious threat to the locator of a new discovery.

Many States provide a procedure to file an amended location notice and still retain the original location date if the earlier location notice contains a minor defect. Such corrections generally involve adjustments of the claim boundaries or reorientation of the claim to align it more with the trend of the vein.

Section 314 of the Federal Land Policy and Management Act requires recordation of the location notice with the State office of the Bureau of Land Management within 90 days of the date of location. A copy of the same notice must also be recorded with the appropriate county recorder's office within 60 to 90 days of the date of location. One should consult State law for the prescribed period.

Exposure of New Reserves or Increase in Mineral Price after Withdrawal

If a discovery did not exist on a claim at the date of withdrawal, a later discovery established by subsequent mineral exposures or rise in mineral commodity prices would not give a claim validity at the date of a hearing.

The Marketability Test

The marketability test has been followed by the Department of the Interior since Layman v. Ellis, 52 LD 714 (1929). The application of the test was expressly upheld in Foster v. Seaton, 271 F2d 836 (DC Cir. 1959). It was further approved by the Supreme Court as a complement to the prudent person test in U.S. v. Coleman, 390 US 602 (1968), which pointed out that "profitability is an important consideration when applying the prudent-man test." See also, Converse v. Udall, 399 F2d 616, 621 (9th Cir. 1968), cert. denied, 393 US 1025 (1969), which indicate that the marketability test is applicable to all mining claims, including those containing precious metals.

The Foster v. Seaton Case

In Foster v. Seaton, supra at 838, the Court upheld the requirement for present marketability followed by the Interior Department since Layman v. Ellis, 52 LD 714 (1929):

> With respect to widespread nonmetallic minerals such as sand and gravel, however, the Department has stressed the additional requirement of present marketability in order to prevent the misappropriation of lands containing these minerals by persons seeking to acquire such lands for purposes other than mining. Thus, such a "mineral locator or applicant, to justify his possession, must show that by reason of accessibility, bona fides in development, proximity to market, existence of present demand, and other factors, the deposit is of such value that it can be mined, removed and disposed of at a profit." [Layman v. Ellis, 54 ID 294, 296 (1933).]

The Coleman Case

In U.S. v. Coleman, supra, Mr. Justice Black, speaking for a unanimous Supreme Court, approved the requirement of the Secretary that "the mineral can be 'extracted, removed and marketed at a profit' - the so-called 'marketability test'" (390 US at 600, 602-603).

Essentially, in Coleman the Court determined that nonmetallic minerals of widespread occurrence must be marketable at a profit. Although the Court said the prudent man test and the marketability test are complementary, this is difficult to reconcile because the prudent man test implies prospective profitability, whereas the marketability test implies present profitability.

Marketability at a Profit

Many recent Department of Interior and Federal court decisions have required marketability at a profit. In U.S. v. Coleman, 390 US 599 (1968), the Supreme Court held that "profitability is an important consideration in applying the prudent man test...." In Roberts v. Morton, 549 F2d 158 (10th Cir. 1977), the Court also indicated that marketability at a profit is relevant to a claim for precious metals.

Proof of Profitable Market

> In U.S. v. Gould, A-30990 (May 7, 1969), the Department of Interior held that it ....does not require a mining claimant to prove a discovery by showing that he is actually engaged in profitable mining operations or even that profitable operations are assured, but it does require a showing of a prospect of profit which is sufficient to invite reasonable men to expend their means in attempting to reap that profit by extracting and marketing the mineral, as distinguished from evidence of value which will entice men to invest their money only in gaining control over land and holding it in the hope or expectation that at a future date the land may be found to be valuable for the minerals which it contains.

In Barrows v. Hickel, 447 F2d 80, 82 (9th Cir. 1971), the Court held that "actual successful exploitation of a mining claim is not required to satisfy the prudent man test."

Amount of Profit

One of the most common questions by claimants concerning the profitability requirement is how much profit is necessary to validate a claim. In several interesting cases the Interior Department addressed the profitability requirement in terms of the amount of profit necessary to establish a discovery. In U.S. v. Barrows, A-31023 (November 28, 1969), the Board held that a profit as low as $245 per year would not satisfy the prudent man test of discovery.

In U.S. v. Penrose, 10 IBLA 334 (1973) the Board indicated that although a sale of $1.00 could represent a profit to a claimant, it would not meet the prudent-person test.

Marketability Applies to All Minerals

The question of whether the marketability test is applicable to intrinsically valuable minerals such as base and precious metals has been considered in a number of cases. In Converse v. Udall, 399 F2d 616 (1968), perhaps the most frequently-cited case on this subject, the court held that the marketability test, including the profit factor, was applicable to all mining claims including those containing precious metals.

Presently Marketable at a Profit: New Definition

The Interior Board of Land Appeals has significantly refined the prudent-person test by defining "presently marketable at a profit" to mean that the claimant "must show that as a present fact, considering historic price and cost factors and assuming that they will continue, there is a reasonable likelihood of success that a paying mine can be developed." [In re Pacific Coast Molybdenum, 78 IBLA 16, 29, 90 I.D. 352 (1983).] This new definition was made in response to large fluctuations in mineral commodity prices that occurred during the preceding five years. Now a claimant is not stuck with the latest market price of a commodity, but instead may average prices over an appropriate period of time. The Board, however, did caution that "situations can occur in which structural economic changes or technological breakthroughs invalidate historical conditions as a guide to present marketability." For example, mineral prices elevated artificially by Government price supports would not be relevant to the question of present marketability. Also the possibility that a future stockpiling program might someday be initiated would be "essentially speculative and could not serve as a predicate upon which a prudent man would have proceeded to expend time and money with a reasonable hope of success." [Id at 30.]

Market Too Small for Profitable Operation

In U.S. v. Husman, 81 IBLA 271, 278 (1984), the Board determined that there was a market for chemical-grade (locatable) limestone; however, this market could not support an operation of the size necessary to establish a profitable operation.

Tenth Circuit Approves Presumption of Invalidity Where Lack of Development

In U.S. v. Zweifel, 508 F2d 1150 (10th Cir. 1975), the Tenth Circuit Court approved the Interior Department's requirement concerning the presumption of invalidity where claims were held several years with no development. The Court said:

> If mining claimants have held claims for several years and have attempted little or no development or operations, a presumption is raised that the claimants have failed to discover valuable mineral deposits or that the market value of discovered minerals was not sufficient to justify the costs of extraction. [508 F2d at 1156, n.5.]

Lack of Marketing (Sales) is Not Proof of Invalidity

In Rodgers v. U.S., 726 F2d 1376, 1379 (9th Cir. 1984), it was held that "although lack of actual marketing of the mineral by the claimant may be relevant to the question of marketability, it is not conclusive proof of invalidity of claim. And on the same point, the Court in Barrows v. Hickel, 447 F2d 80, 82 (9th Cir. 1971) said that "actual successful exploitation of a mining claim is not required to satisfy the "prudent man test." In Rodgers v. U.S., supra, the Court apparently accepted a lack of sales because the claimants "needed to accumulate an inventory before breaking into foreign market."

Proof of Evidence of Sales Records

In a number of Interior Department and Federal court cases, it has been held that it is the responsibility of the claimant to maintain adequate business records relating to both sales of the mineral product and costs of production.

U.S. v. Arbo, 70 IBLA 244 (1983) is an excellent example of where a claimant had no record of sales. Although the appellant supplied a number of receipts indicating sales of gold to several different companies, he was not able to show the costs of producing the gold or even to document that the gold came from the contested claim. It is not uncommon for the owner of a placer-gold claim to have a poor record of receipts in some cases because the gold is recovered in a highly marketable condition and there may be a temptation to market the gold in such a manner as to avoid income taxes. However, as the Board points out below, you cannot have it both ways, i.e., get credit for sales in a contest action for which there is no income tax record of sales.

Marketability Must Not Depend on Value Added by Manufacture

It is well established that marketability of a mineral must be based on the mineral in its raw state rather than depend on value added by manufacture. In U.S. v. Mansfield, 35 IBLA 95 (1978), it was held that "any determination of the value of the contestee's claims, must rest on the marketability of the obsidian in its rough form and not upon any enhanced value from subsequent processing or craft work."

Marketing of Comparable Material from Other Claims

In Melluzzo v. Morton, 534 F2d 860, 863 (9th Cir. 1976), the Court held that a "claimant need not rely on his own successful marketing efforts to prove marketability of his material. If the successful marketing by others has sufficiently established that the claimant's comparable material is itself marketable, that can suffice." It should be pointed out that in this case the Court was making reference as to how sales of material by one claimant may establish marketability for another claimant who has comparable material but no record of marketability.

In Rodgers v. U.S., supra, the Court held that the successful marketing by a claimant of a gem material from one claim in a claim group could satisfy marketability for the other claims that had comparable material. The Court also indicated that this concept of comparable material would apply even though the market was already preempted by the producing claims and that there is an abundance of comparable material from other sources in the area.

In Dredge Corp. v. Conn, 733 F2d 704, 707 (9th Cir. 1984), it was held that "the claimant cannot rely solely on the fact that comparable material is being marketed. Rather, 'the claimant must establish that his material was of a quality that would have met the existing demand, and that it was marketable at a profit.' Melluzzo v. Morton, supra at 863." Dredge Corp. v. Conn, supra at 707. "Proof that neighboring claims are being marketed is relevant to determining a claim's marketability, but such proof alone does not overcome evidence that the market was well supplied. ...Thus, even though comparable claims are being mined, a new claim may be unprofitable because the market has reached such a point of saturation that a new entrant cannot make a profit." [Id at 707.]

Prospective Market or Reserves With No Market

In many parts of the west, minerals subject to the mining law are covered by large claim groups. Where such minerals are widespread with vast reserves, it is not uncommon for the claims or claim groups to cover substantially more reserves than the market could ever absorb. These materials tend to be nonmetallic minerals without intrinsic value such as building stone, sand and gravel, bentonite, silica sand, pumice, perlite and many other construction materials. In Barrows v. Hickel, 447 F2d 80 (9th Cir. 1971), the Court said at 83:

> The marketability test requires claimed materials to possess value as of the time of their discovery. Locations based on speculation that there may at some future date be a market for the discovered material cannot be sustained. What is required is that there be at the time of discovery, a market for the discovered material that is sufficiently profitable to attract the efforts of a person of ordinary prudence.

In Baker v. U.S., 613 F2d 224 (9th Cir. 1980), the Court held that the Board's application of the excess reserves rule exceeded its discretionary and statutory powers, and was arbitrary, capricious, and an abuse of discretion. Thus, the Court held that there can be no such thing as an "excess reserves test" or a "too much test."

In Oneida Perlite, 57 IBLA 167 (1981), the Board gave a thorough review of the case law on the subject of reserves for which there is no market. The Board defined "reasonable" reserves as follows:

> What amount of reserves is "reasonable" is a determination to be decided on the basis of the evidence in each case. The nature of the mineral, its unit value, the extent of the market, and whether it is expanding or diminishing, the amount of similar mineral which can supply that market from other sources, might all bear on the question of whether the location of additional claims for the same mineral was justified as the act of a prudent man in the reasonable belief that by the expenditure of his labor and means a valuable mine might be developed on each such claim.

The Board concluded its lengthy decision by giving the present status of the term "excess reserve" and stating that the real issue is marketability or economics. The Board said:

> As hereinbefore indicated, a reference to "excess reserves" does not describe a new rule of law invented by this Department, or a superimposition of a new test of a claim's validity on the existing law. It is nothing more or less than a descriptive phrase applicable to a particular set of circumstances. It describes the location of claims for far more land and mineral than reason and prudence would allow because there is such a superabun-

dance of the material that the market simply cannot accept all of it at a profit. Therefore, some of the deposits must be regarded as not valuable in an economic sense. This concern for excess reserves is rooted in the basic statute, 30 USC Sec. 22 (1976), and controlled by the "prudent man" test of discovery as complemented by the requirement that the economic value of the deposit be measured by a determination of whether it is presently marketable at a profit. In the making of this determination, it is appropriate to consider the magnitude and sources of other supplies of that mineral to the same market.

Hypothetical Market at a Critical Date

The Act of July 23, 1955, as well as many withdrawal actions have caused certain minerals to no longer be open to location under the mining law. However, valid claims for such minerals existing at the date of the withdrawal remain valid so long as a discovery existed then and continues to the present. When the United States investigates the validity of such claims, it is necessary to apply the marketability test at both the critical date and the present. In cases where minerals from a claim were not being mined and marketed at the critical date, it must be determined whether or not the minerals, if produced, could've been (theoretically) marketed.

Continuous Operation is not Required During Critical Period

In Charlestone Stone Products Co., Inc. v. Andrus, 553 F2d 1209 (9th Cir. 1977), reversed in part on other grounds, 436 US 604 (1978), the Court held that failure of a claimant to maintain continuous operations during a critical period is not required for proving validity of a claim. A "critical period" refers to that period of time between the date of withdrawal and the present time during which a showing of marketability must be maintained.

In Rawls v. U.S., 566 F2d 1373 (1978), the Court held that "absence of sales in the critical period, though relevant, will not alone support a finding of unmarketability and nondiscovery. When there is little or no evidence of pre-1955 sales, a court should consider costs of extraction, preparation and transport as well as the level of then-existent market demand."

Common and Uncommon Varieties

Statutory Authority for Disposing Common Variety Minerals

Section 601 of Title 30 of the United States Code authorizes the Secretary of the Interior to sell "common varieties" of "sand, stone, gravel, pumice, pumicite, cinders and clay." On July 23, 1955, Public Law 167 (69 Stat. 368; 30 USC 611) was passed to, among other things, prohibit further location of common variety minerals. The Act stated in part:

> No deposit of common varieties of sand, stone, gravel, pumice, pumicite, or cinders and no deposit of petrified wood shall be deemed a valuable mineral deposit within the meaning of the mining laws of the United States so as to give effective validity to any mining claim hereafter located under such mining laws.

However, the Act went on to provide for an exception to "uncommon variety" minerals at 30 USC 611:

> Common varieties as used in sections 601, 603, and 611 to 615 of this title does not include deposits of such materials which are valuable because the deposit has some property giving it distinct and special value and does not include so-called "block pumice" which occurs in nature in pieces having one dimension of two inches or more.

Therefore, the statute clearly implies that "uncommon varieties" of such materials exist and are still locatable under the mining law. Uncommon varieties are "valuable because the deposit has some property giving it distinct and special value ...."

As a basis for determining under what circumstances a deposit of "sand, stone, gravel, pumice or cinders" may be located, the remainder of this chapter is primarily devoted to what the Federal Courts and Interior Department have interpreted the phrase "property giving it distinct and special value" to mean.

The Interior Department has attempted, with little success, to define "common varieties" by regulation (43 CFR 3711.1(b)):

> "Common varieties" includes deposits which, although they may have value for use in trade, manufacture, the sciences, or in the mechanical or ornamental arts, do not posses a distinct, special economic value for such use over and above the normal uses of the general run of such deposits. Mineral materials which

occur commonly shall not be deemed to be "common varieties" if a particular deposit has distinct and special properties making it commercially valuable for use in a manufacturing, industrial, or processing operation. In the determination of commercial value, such factors may be considered as quality and quantity of the deposit, geographical location, proximity to market or point of utilization, accessibility to transportation, requirements for reasonable reserves consistent with usual industry practices to serve existing or proposed manufacturing, industrial, or processing facilities, and feasible methods for mining and removal of the material. Limestone suitable for use in the production of cement, metallurgical or chemical grade limestone, gypsum, and the like are not "common varieties." This subsection does not relieve a claimant from any requirements of the mining laws.

Stone Versus Mineral or Element

Because common varieties of sand, stone, gravel, pumice, pumicite or cinders generally consist of an aggregate of two or more elements and (or) minerals, the properties of each are not particularly significant. It is important to note that in this context we are talking about minerals in the "scientific" sense rather than the "legal" or "economic" sense. In fact, it is quite uncommon for minerals to be used in the scientific sense in any Interior or court decision. However, in U.S. v. Pierce, 75 ID 270 (1968); U.S. v. Bunkowski, 79 ID 47 (1972); and U.S. v. Beal, 23 IBLA 378 (1976), the Board did use the term "mineral" as a geologist would.

As an example of how the Board made a distinctionn between "stone" and "mineral" in Pierce, Bunkowski, and Beal, suppose that a mineral such as feldspar is extracted and used for a particular purpose that requires its physical and (or) chemical properties. This is not a common-variety situation regardless of whether the feldspar is mined as an individual mineral or as granite (a stone or rock) containing several minerals such as mica and quartz in addition to the mineral feldspar.

In general, if the rock is valuable for only an individual mineral or element such as gold, silver, feldspar, mica, etc., it is not a common - variety question and 30 USC 611 does not apply; however, if the entire rock is used and the constituent elements or minerals are relatively unimportant, then 30 USC 611 may apply.

Unique Property Gives Special Use or Higher Price in Market Place

In U.S. Minerals Development Corp., 75 ID 127 (1968), one of the early and important common variety cases, the Board held that for a deposit to be an uncommon variety, it must satisfy the following criteria: (1) The deposit must have a unique property, (2) The unique property must give the deposit a distinct and special value, (3) The value may be for some use to which ordinary varieties of the mineral cannot be put, or (4) The material must sell at a higher price than material in other deposits without such property is sold.

Guidelines to Distinguish between Common And Uncommon Varieties

In McClarty v. Secretary of the Interior, 408 F2d 907, 908 (9th Cir. 1969), the Court set forth standards to distinguish between common varieties and uncommon varieties of material, thus approving U.S. Mineral Development Corp., supra. The Court said at 908:

In the U.S. Minerals Development Corporation case, the Secretary, impelled by the Coleman decision to breathe some life into the building-stone statute, has defined guidelines for distinguishing between common varieties and uncommon varieties of building stone. These guidelines, as we discern them, are (1) there must be a comparison of the mineral deposit in question with other deposits of such materials generally; (2) the mineral deposit in question must have a unique property; (3) the unique property must give the deposit a distinct and special value; (4) if the special value is for uses to which ordinary varieties of the mineral are put, the deposit must have some distinct and special value for such use; and (5) the distinct and special value must be reflected by the higher price which the material commands in the market place.

Lower Overhead and Greater Profits

In McClarty v. Secretary of the Interior, supra at 909, the Court suggested that the distinct and special value of a stone may not be measurable by a comparison with the price of other building stones; and that the unique property of the deposit might allow lower costs of mining and thus greater profits.

Intrinsic Factors Distinguished from Extrinsic Factors

The Interior Board of Land Appeals had held in a number of cases that unique properties that give a deposit a distinct and special value must be inherently intrinsic to the deposit. Extrinsic factors such as scarcity, proximity to market, value added by manufacture or marketing techniques and other external factors unrelated to the deposit itself are not counted towards giving a deposit a distinct and special value.

Immense Quantities Indicate Common Variety

In U.S. v. Coleman, supra at 603-604, the United States Supreme Court said "we believe that the Secretary of the Interior was... correct in ruling that in view of the immense quantities of identical stone found in the area outside the claims, the stone must be considered a common variety."

Stone In Question Must Be Compared With Common Varieties

In U.S. v. Vaughn, 56 IBLA 247 (1981), the Board held that "it is a prerequisite for an adequate comparison that the stone in question be compared with deposits of common varieties in order to determine if it has a distinct and special value reflected by a higher market value."

Comparison Must Be With All Deposits Rather Than Uncommon Varieties

In U.S. v. Kaycee Bentonite Corp., 64 IBLA 186, 207-209 (1982), the Board reviewed a number of cases where it was held that the comparison of a deposit of stone may be with all deposits, or limited to similar deposits. The Board held that the comparison should be with all deposits generally if (1) the deposit is marketable for purposes that are not typical of common variety minerals, and (2) the material is not widespread.

Comparison Made With Stone in Immediate Region

According to U.S. v. Smith, 66 IBLA 182, 189 (1982), the Board held that the comparison may be made with other stone in the immediate region in active quarries and exposed outcrops. If stone in exposed outcrops may be used in the comparison, one is not restricted to only those deposits that are mined and marketed.

Comparison With Other Minerals on Per Unit Basis

The Board in U.S. v. McClarty, 17 IBLA 20, 46 (1974) said that materials must be compared on a "per unit" basis rather than on volume or quantity of material sold.

Comparable Deposits Marketed by Others

Melluzzo v. Morton, 534 F2d 860 (9th Cir. 1976) gives authority to prove marketability where successful marketing by others has established that the claimant's undeveloped but comparable material is marketable.

Unique Properties Distinguished from High Quality Material

Even though the material on a claim is of a better quality than other material found generally in the area, the Department has held in several cases that the fact that deposits may have characteristics superior to those of other deposits (but do not give it special and distinct value) does not make them an uncommon variety so long as they are used only for the same purposes as other deposits that are widely and readily available. [U.S. v. Guzman, 81 ID 685 (1974); U.S. v. Harenberg, 9 IBLA 77 (1973).]

Aggregates of Profits from Sales of Common and Uncommon Varieties

In many cases a claim may contain deposits of both common and uncommon variety minerals. For example, a claim may embrace layers of very pure metallurgical-grade limestone interbedded with layers that do not qualify as metallurgical grade. If the claimant should be necessity mine both grades and sell the lower-grade limestone for some common variety use, he cannot include profits from the sale with profits derived from sale of the metallurgical-grade limestone to show marketability. The common variety limestone must be purchased by contract as required by 30 USC 601.

In U.S. v. Lease, 6 IBLA 19, 25-26 (1972), the Board considered a case involving aggregation of profits from sales of metallurgical-grade dolomite and common variety dolomite.

In U.S. v. Forsesyth, 15 IBLA 43, 59-60 (1974), the Board again said that with different grades of limestone, you cannot aggregate the profits of the common and uncommon variety minerals; but instead, you must treat the common variety limestone as waste with no value, even if it must be mined in order to extract the uncommon variety deposit.

In U.S. v. Mansfield, 35 IBLA 95 (1978), the Board considered a case involving the aggregation of profits from several grades of obsidian.

Gold or Other Locatable Minerals with Common Variety Minerals

The question of whether gold can be claimed if it is contained in common variety material such as sand and gravel was addressed by section 3 of the Act of July 23, 1955, which provides as follows:

> That nothing herein shall affect the validity of any mining location based upon discovery of some other mineral occurring in or in association with such a deposit (of common variety sand, stone, etc.)....

This provision refers to the discovery of some locatable mineral such as gold occurring in a deposit of a common variety sand and gravel. Congress did not intend that the presence of gold within such a deposit would validate the claim, rather, there must be a discovery of gold within the meaning of the mining laws. The fact that a mineral like gold occurred in a nonlocatable deposit of sand and gravel would not invalidate the claim if it were otherwise valid because of the discovery of gold under this standard. However, likewise, the value of the sand and gravel would not be considered in evaluating the value of the gold to determine if there was a valuable deposit of gold.

Sand and Gravel Deposits That Have Never Been Locatable

Sand or gravel used as fill, subbase or ballast has never been locatable. [U.S. v. Osborn (Supp on Judicial Remand), 28 IBLA 13 (1976).]

Sand and Gravel Deposits Not Locatable After July 23, 1955

In U.S. v. Henderson, 68 ID 26, 29-30 (1961), the Department considered a sand and gravel deposit (free of caliche and other impurities) in which it was possible to use or sell pit-run material meeting construction specifications of concrete aggregate. In Henderson, supra, the Board said:

> The fact that these sand and gravel deposits may have characteristics superior to those of other sand and gravel deposits does not make them an uncommon variety of sand and gravel so long as they are used only for the same purposes as other deposits which are widely and readily available.

If, however, such a claim was valid and existing on July 23, 1955 and met the marketability test from then until the present, the claim would be valid.

The Department has consistently held that sand and gravel deposits suitable for road base, asphalt-mix and concrete aggregate without expensive processing, but which are aused only for the same purposes as other widely available, but less desirable deposits of sand and gravel, are common varieties. [U.S. v. Ramstad, A-30351 (September 24, 1965).]

The McCormick Case: An Uncommon Variety Sand and Gravel

In U.S. v. McCormick, 27 IBLA 65, 68-69, 83-84 (1976), the Board held that the sand and gravel deposit in question was an uncommon variety. this is one of the very few sand and gravel deposits to ever qualify as an uncommon variety, and for this reason should be read carefully to develop an understanding of the types of properties and/or uses that make such a mineral locatable even after July 23 1955. It should be noted in reading this case that the Board applied to sand and gravel many of the principles previously established for building stone. The Board said:

> We conclude the merits of the case demand a holding that the material is locatable. The evidence establishes the following special characteristics of the deposit which translate directly into special and substantial economic values: (1) No drilling, blasting, or ripping is required, (2) No "primary" crushing (to reduce the rock to minus 15 inces) is required, (3) Three of four purchaseres testified that no "secondary" crushing was required, (4) There is little or no overburden, (5) The material is naturally sorted by type, no sorting or classification is required beyond screening to eliminate oversize, (6) The waste factor is very much lower than at other area pits, (7) The material is naturally clean, requiring no washing, (8) No blending of fine or coarse aggregates is necessary to meet specifications, (9) Because the material is significantly lighter in weight than competing aggregates, a ton of the subject material will ocver a 20 percent greater area, and (10) The material can be used without the addition of expensive lime or commercial anti-stripping agents.

Gem Stones and Gem Minerals

Gem stone and gem minerals are discussed together in this section even though many gem minerals are elements or minerals as described in Pierce, supra; and therefore are neither common or uncommon varieties.

Gem stones and minerals held to be locatable in early cases include: (1) onyx - Utah Onyx Development Co., 38 LD 504 (1910); (2) marble - Pacific Coast Marble Co. V. Northern Pacific R.R. Co., 25 LD 233 (1897); and diamonds - 14 Op. Atty, Gen, 115, 1872.

Value of Gemstones as Found on Claims Rather Than Enhanced Value

In U.S. v. Stevens, 14 IBLA 380 (1974), the Board determined that even though many stones will take a polish and have an enhanced value because of it, "it is the value of the stone deposit as it is found on the claims that is the important fact." In other words, if a gemstone such as "chert" or "jasper" is to be an uncommon variety, it is the value of the stone in its uncut or unpolished state that must be compared with other "stone formations."

Obsidian is a Common Variety Mineral

In U.S. v. Mansfield, 1978, the Board determined that the ability of obsidian to take polish does not make it an uncommon variety. In this case, it was held that obsidian was held to be a common variety because it exits "in almost limitless quantities."

Gemstone Permits Do Not Apply Towards Validity

The mining laws do not authorize the sale of permits to take or enjoy gemstones; and any such sales would not be considered in determining the validity of a claim. [U.S. v. Stevens, 14 IBLA 380 (1973).]

Geodes Are Uncommon Variety Minerals

In U.S. v. Bolinder, 28 IBLA 192 (1976), the Board held that geodes are an uncommon variety mineral and should not be compared with other geode deposits but instead should be compared with "other stone formations."

Locatable Grades of Limestone

In U.S. v. Forsesyth, 15 IBLA 43, 59 (1974), the Board upheld U.S. v. Chas. Pfizer & Co., Inc., 76 ID 331 (1969) in which limestone containing 95 percent or more calcium and magnesium carbonates was determined to be an uncommon variety.

Limestone Used as Concrete Aggregate or Soil Additives

In U.S. v. Alaska Limestone Corp., 66 IBLA 316, 324 (1982), the Board held that limestone deposits cannot be located after July 23, 1955 for use as concrete aggregate or soil additives.

Limestone Used in Manufacture of Cement is Uncommon Variety

Although limestone used in the manufacture of cement is an uncommon variety, it must still meet the requirements of discovery including marketability at a profit. [U.S. v. Alaska Limestone Corp., supra at 318.]

Cinders and Other Volcanic Products

In U.S. v. Harenberg, 9 IBLA 77 (1973), the Board held that volcanic cinders used in the manufacture of cement blocks is a common variety mineral.

Volcanic rock useful as a filter rock in sewage treatment plants may be an uncommon variety mineral. [U.S. v. Clark County Gravel, Rock and Concrete Company, A-31025 (March 27, 1970).]

Soil Amendments

In U.S. v. Bunkowski, 79 ID 43 (1972), it was held that when a mineral is used as a soil amendment, it must cause a chemical change to the soil rather than a physical change.

Introduction to Clay

The most comprehensive decision concerning the locatability of clay is undoubtedly U.S. v. Peck, 29 IBLA 357, 84 ID 137 (1977). Of particular significance in Peck is the Board's distinction between "common" or "ordinary" clay not considered a "valuable mineral deposit" and deposits of clay having exceptional qualities useful for purposes for which common clay cannot be used.

1. Common Clay (salable):
   In referring to "common clay" not locatable under the mining laws, the precedents demonstrate that clay used only for structural brick, tile, and other heavy clay products, and pressed or face brick, falls within that classification. They also demonstrate that clay deposits useful only for pottery, earthenware, or stoneware that cannot meet the refractory and other quality standards for high-grade ceramic products, such as china, come within that classification.

2. Exceptional Clay (locatable):
   The exceptional qualities that have been recognized as taking a deposit outside the classification of a common or ordinary clay within the meaning of the mining laws are, as mentioned, clays having sufficiently high refractoriness to meet the standards for products requiring such special qualities. In addition, certain clays with special characteristics that make them

useful for particular uses, as in the oil and oil-well-drilling industries, outside the manufacture of general clay-products, have been considered locatable.

The Kaycee Bentonite Case

In U.S. v. Kaycee Bentonite Corp., 64 IBLA 186 (1982), the Board upheld a decision of Administrative Law in which Judge Mesch declared five mining claims null and void and 125 mining claims valid because the claims contain deposits of exceptional clay. Judge Mesch held that if a claimant can establish that a deposit of bentonite is marketable for purposes for which common clay cannot be used, the deposit is locatable. Bentonite, the "exceptional clay" in this case, is used as a binder in pelletizing taconite. Approximately eighty percent of the steel produced in the United States is made from pellets of taconite.

Pertinent points from Kaycee Bentonite are: (1) Even if blending is required, bentonite is still an exceptional clay (64 IBLA at 217), (2) Bentonite must meet the marketability test (64 IBLA at 217), and (3) Widespread minerals may be locatable.

Standards to Distinguish Common Varieties and Uncommon Varieties

In Massirio v. Western Hills Mining Association, 78 IBLA 155 (1983), the Board stated that the following standards to "distinguish between common varieties and uncommon varieties of material" were set forth in McClarty v. Secretary of the Interior, 408 F2d 907, 908-09 (9th Cir. 1969): (1) There must be a comparison of the mineral deposit in question with the other deposits of such minerals generally, (2) The mineral deposit in question must have a unique property, (3) The unique property must give the deposit a distinct and special value, (4) If the special value is for uses to which ordinary varieties of the mineral are put, the deposit must have some distinct and special value for such use, and (5) The distinct and special value must be reflected by the high price which the material commands in the market place, or by reduced cost or overhead so that the profit to the claimant would be substantially more.

FEDERAL MINERAL LEASING

The Mineral Leasing Act of 1920, as amended (30 USC 181 et seq.) provides that "deposits of coal, phosphate, sodium, potassium, oil, oil shale, native asphalt, solid and semisolid bitumen, and bituminous rock (including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined or quarried) or gas, and lands containing such deposits owned by the United States" may be acquired only through a leasing system. For the most up-to-date and detailed requirements concerning Federal leasable minerals one should consult the most recent volume or Title 43 of the Code of Federal Regulations. Because these regulations are under constant revision, it is also a good practice to check the "Cumulative List of Sections Affected", which gives a monthly update on new regulations, and the "Cumulative List of Parts Affected", which appears in each issue of the Federal Register. Federal leasable minerals are covered in the following parts of the Code of Federal Regulations: Part 3100 - Oil and Gas Leasing; Part 3200 - Geothermal Resources Leasing; Part 3300 - Outer Continental Shelf Minerals; Part 3400 - Coal Management; and Part 3500 - Leasing of Minerals other than the above.

Authority - Public Domain

The basic statute for mineral leasing on public domain lands is the Mineral Leasing Act of February 25, 1920 (41 Stat. 437; 30 USC Sec. 181 et seq.), as amended and supplemented.

Leasable Minerals - Public Domain

The Mineral Leasing Act of 1920, as amended, authorizes that specific minerals shall be disposed of through a leasing system. Minerals designated as leasable under this law include: 1. Phophate; 2. Native asphalt, solid and semisolid bitumen and bituminous rock including oil-impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined; 3. Sulphur in the states of Louisiana and New Mexico; and 4. Chlorides, sulfates, carbonates, borates, silicates, or nitrates of potassium and sodium.

Authority - Acquired Lands

Minerals in acquired lands may be leased pursuant to the Mineral Leasing Act for Acquired Lands (61 Stat. 913; 30 USC 351-359). This law was enacted on August 7, 1947, Section 402 of Reorganization Plan No. 3 of 1946 (60 Stat. 1099) transferred the function of leasing and disposal of minerals in certain acquired lands from the Secretary of Agriculture to the Secretary of the Interior.

Leasable Minerals - Acquired Lands

All minerals that now qualify as locatable minerals in public domain lands may in some cases be obtained through a mineral lease on acquired lands. Leasable Minerals in this category would include gold, silver, copper, gems, uranium, etc. Also, all minerals designated by the Mineral Leasing Act of 1920 as leasable in public domain lands are leasable in acquired lands.

Filing Procedure

Application for leases or permits are filed with the appropriate fees in the land office of the Bureau of Land Management of the state in which the permits or leases are sought. When an application is received in the land office, it is date-stamped to establish priority and a serial number is assigned. The application is then copied and placed on the public counter for review by interested persons. A serial page is prepared for each application and is placed in the Serial Register Book in chronological order. When leases are issued, assigned or terminated, an entry describing the action is made on the serial page. A separate use township plat is prepared for each mineral under lease or permit. For example, all oil and gas leases in a township are delineated on an oil and gas plat, all coal leases in the same township are delineated on a coal plat and all geothermal resources leases are delineated on a geothermal resource plat.

Prospecting Permit

A prospecting permit allows the permittee an exclusive right to prospect and explore within a permit area to establish the existence of valuable minerals. The permittee is allowed to remove only such deposits as necessary to conduct experimental studies and must keep a record of all minerals removed. A prospecting permit does not authorize mining in commercial quantities.

Term - Prospecting Permits

Prospecting permits are normally issued for a term of two years. A phosphate permit may be extended for a period of four years if certain conditions are met.

Preference-Right Lease Applications

Applications for a preference-right lease must be filed in the land office not later than 30 days after the prospecting permit expires.

Acreage Limitations - Acquired Lands

The amount of acquired lands that may be held by a permittee or leasee may not exceed the amount that may be held on public domain lands under the mineral leasing laws. Permit and lease holdings on public domain lands do not count against such holdings on acquired lands.

Minerals that are currently locatable under the General Mining Law of 1872 in public domain lands are available only through a mineral lease in acquired lands. No person is allowed to hold more than 20,480 acres under lease and permit in any one state. A prospecting permit may not exceed 2,560 acres and must fit within an area of six miles square or within an area not exceeding six surveyed sections in length or width.

Term - Leases

Leases are issued for a primary term of 20 years and are subject to readjustment of terms if the lease is to be renewed. Asphalt leases are issued for a primary term of 10 years. Hardrock mineral leases for acquired lands have a term that is established by the BLM but cannot exceed 20 years.

SALABLE MINERALS IN BUREAU OF LAND MANAGEMENT-ADMINISTERED LANDS

Authority

The Materials Act of July 31, 1947 (61 Stat. 681), amended by the Acts of July 23, 1955 (PL-167; 69 Stat. 367) and September 28, 1962 (PL-87-713), authorized that certain mineral materials be disposed either through a contract-of-sale or a free-use permit. This group of mineral materials, commonly known as "salable minerals" includes, but is not limited to, petrified wood and common varieties of sand, stone, gravel, pumicite, cinders, and clay on public lands of the United States, 30 USC 601 (1976).

Effect on Mining Claims and Other Surface Uses

Mineral-material disposals are not made where there are valid existing claims. Any subsequent mining location or mineral lease covering lands under a contract-of-sale for mineral materials is subject to the outstanding contract-of-sale. The United States reserves the right to continue to use the surface of lands under contract-of-sale for leases, licenses and permits concerning other resources; however, these subsequent leases must not interfere with the extraction or removal of the mineral material. Removal of mineral materials from the public lands without authorization is an act of trespass.

Community Pits

The regulations (4 CFR 3604.1) provide for the establishment of community pits to be used by the general public to remove small amounts of material after obtaining a nonexclusive permit from the district manager of the Bureau of Land Management. A fee is charged for each cubic yard or ton of gravel removed plus an amount necessary to reclaim the site upon depletion of the pit.

Common Use Areas

Common use areas, like community pits, are established for nonexclusive disposals of mineral materials where the removal of materials would cause only a negligible surface disturbance. 43 CFR 3604.1.

Appraisal of Mineral Materials

Mineral materials are not sold at less than the appraised value. Also, a reappraisal is necessary every two years. 43 CFR 3610.1-2.

Noncompetitive Sales

Noncompetitive sales may be made where it is impracticable to obtain competition and it is in the public interest. Individual sales, not to exceed 100,000 cubic yards may be made without advertising or calling for bids. The total aggregate of sales to an individual must not exceed 200,000 cubic yards in any one state during a twelve month period. [43 CFR 3610.2-1.] The term of contract for noncompetitive sales is not to exceed five years, excluding extension and removal periods. 43 CFR 3610.2-4.

Competitive Sales

All sales are made through competitive bidding unless excluded for the reasons above. Sales are advertised in a newspaper of general circulation in the area where the material is located. A notice of sale is published once a week for two consecutive weeks giving the location of the lands, the material offered, type of materials, quantities, appraised price and the procedure for bidding. Written sealed bids, oral bids or both may be required, together with a bid deposit of not less than 10 percent of the appraised value of the mineral materials. The contract is awarded to the highest qualified bidder. The term for competitive contracts is not to exceed 10 years, excluding extension or removal periods. 43-CFR 3610.3.

Free-Use Permits

Free-use permits are issued for a period not to exceed one year; however, a maximum term of 10 years is allowed for government agencies and municipalities. Material acquired under a free-use permit must be for the permittee's own use and may not be traded or sold. There is no limitation on the number of permits or the amount or value of the material if the permit is issued to a government agency or municipality for use on a public project. A free-use permit issued to a non-profit association or corporation must not allow disposal of more than 5,000 cubic yards in any period of twelve consecutive months. [43 CFR 3621.1.]

Mining Claims and Leases are Subject to Contracts

Lands covered by material-sale contracts or free-use permits are subject to location and entry under the mining and mineral leasing laws. [U.S. v. McClarty, 81 ID 472 (1974).] However the regulations in 43 CFR 3601.1-2(c) state that "any person that has a subsequent settlement, location, lease, sale or other appropriation under the general land laws, including the mineral leasing and mining law on lands covered by a material-sale contract or free-use permit, shall be subject to the existing use authorization."

SALABLE MINERALS IN U.S. FOREST SERVICE-ADMINISTERED LANDS

(36 CFR 251.4)

Authority

Mineral materials are disposed of from the National Forest System under the authority of the Act of July 31, 1947 (61 Stat. 681), as amended by the Act of August 31, 1950 (64 Stat. 571), and the Act of July 23, 1955 (69 Stat. 367; 30 USC 601-603) and pursuant to the Act of June 11, 1960 (74 Stat. 205). The Forest Ranger may dispose of common varieties of sand, stone, gravel, pumice, pumicite, cinders and clay.

Free Use

All mineral material must be appraised and sold at not less than the appraised value, except material disposed of to Federal or State agencies, municipalities or non-profit organizations. These agencies and organizations may receive the material without charge, provided the materials are not used for commercial purposes or resale and provided the site is reclaimed to productive use.

If the appraised value of the material exceeds $1,000, it must be sold to the highest bidder at public auction. Notice of sale must be published once each week for four consecutive weeks in a newspaper having general circulation in the county in which the material is located. The competitive sale may be by sealed bid or auction.

Appraised Value Less than $1,000

If the appraised value is $1,000 or less, the material may be sold to a qualified applicant by Special Use Permit; however, no more than $1,000 worth of materials may be sold to any one applicant in any one area in any one period of 12 consecutive months.

Mining Industrial Minerals on Arizona State Trust Land

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The mineral estate of Arizona's State Trust lands, which are administered by the State Land Department for the benefit of the common schools and 14 other beneficiaries, totals more than 10.5 million acres, or almost 15 percent of the State's entire area. Trust lands exist in all 15 of the State's counties, with the most and least acreage found in Yavapai and Gila Counties, respectively.

Revenues derived from the Trust mineral estate include royalties, rentals, and fees. In Fiscal Year 1983-84, these revenues amounted to $4.2 million, or 13.5 percent of all income received by the Trust during this period. Industrial minerals, led by sand and gravel, contributed $1.1 million from 82 active properties.

The right to mine and ship minerals from State Trust lands is acquired in one of two ways, by mineral lease or by mineral-materials sales agreement. Locatable mineral deposits such as gypsum or zeolites are leasable, but common mineral materials such as decomposed granite fall in the sales-agreement category.

The department has about 650 mineral leases on its active rolls, of which 130 are for industrial minerals. A breakdown of these 130 leases by commodity is as follows: limestone/marble (57), gypsum (21), zeolites (13), pumice (10), bentonite (8), building or decorative stone (6), mica (6), clay (5), magnetite sands (2), feldspar (1), and slate (1). Less than 28 percent of these leases have ever paid production royalties to the Trust. Many of the nonproductive leases are being held for reserve purposes, but others lack development capital or markets. In Fiscal Year 1983-84, leases accounted for only 2.7 percent of total industrial-mineral income.

The department holds 310 mineral-materials sales agreements: 241 with the Arizona Department of Transportation, 30 with other government agencies, and 39 with private concerns. Sand-and-gravel deposits and highway construction materials make up the bulk of the 310 sales agreements; other commodities include common clays, decomposed granite, cinders, and building stone.

Leases for industrial minerals cover 10 of Arizona's 15 counties. Table 1 shows the geographic distribution of these leases by commodity.

Common mineral materials being mined or quarried on Trust lands by private concerns are geographically distributed as shown in Table 2.

Table 1. *Distribution by county of industrial minerals under State lease, listed in decreasing order of number of leases.*

COMMODITY	COUNTY or COUNTIES
Limestone/Marble	Apache, Cochise, Gila, Pima, Pinal, Yavapai
Gypsum	Mohave, Pinal, Yavapai
Zeolites	Cochise, Graham
Pumice	Yavapai
Bentonite	Apache
Building Stone	Coconino, Mohave
Mica	Mohave
Clay	Pima
Magnetite Sands	Pinal
Feldspar	Maricopa
Slate	Maricopa

Table 2. *Distribution by county of common industrial-mineral materials being mined or quarried from Trust lands by private concerns.*

COMMODITY	COUNTY or COUNTIES
Building Stone	Coconino
Cinders	Apache, Coconino
Clay	Pima
Decomposed Granite	Maricopa, Pinal
Sand and Gravel	Apache, Coconino, Maricopa, Mohave, Pima, Pinal, Yuma

The mechanics of obtaining a mineral lease or mineral-materials sales agreement from the Land Department will not be dealt with here. Some comments, however, should be made concerning certain aspects of the application process. Lease- and sales-agreement applications have a number of things in common including (1) the requirement for archaeological clearance, (2) input from the Game & Fish Department and other State, county, and occasionally, city agencies, and (3) an approved plan of operation. Both types of contracts require the posting of a restoration and damage bond.

There are several major differences between leases and sales agreements. Leases for industrial minerals are based upon 20-acre mineral claims that conform to the public land survey and require proof of discovery of a valuable mineral deposit for each claim. A mineral lease extends for up to 20 years, with a preferred right to renewal. Unlike a sales agreement, a lease does not require public auction. Sales agreements are active for up to 10 years, but are not renewable. Sales agreements also require a minimum annual guarantee, whereas leases do not. By statute, production royalties for mineral leases are 5 percent of the net value of the extracted materials.

Increased concern over the impact of mining and quarrying operations on the environment, plus a desire to increase the percentage of royalty-paying operations, has led the Land Department to take a stronger position on issuing leases and sales agreements. Applicants for mineral leases must submit much more information than previously required. Because the department will use this information to make a preliminary economic evaluation of a given property, items such as estimated reserves, projected start-up date, production rate, costs, and marketability should be included.

The Land Department's files contain a considerable amount of information that could be helpful to anyone searching for industrial-mineral deposits in Arizona. A visit to the department's Nonrenewable Resources and Minerals Section, at 1624 W. Adams St., Phoenix, Ariz., could prove to be worthwhile.

Minerals and Health: The Asbestos Problem

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ABSTRACT

Of the six forms of asbestos, only three have been used to any significant extent in commerce. These are chrysotile, crocidolite, and amosite. Between 1870 and 1980, approximately 100 million tonnes of asbestos was mined worldwide, of which more than 90 million tonnes was the chrysotile variety, about 2.7 million tonnes the crocidolite variety, and about 2.2 million tonnes the amosite variety.

The three principal diseases related to asbestos exposure are (1) lung cancer, (2) cancer of the pleural and peritoneal membranes (mesothelioma), and (3) asbestosis, a condition in which the lung tissue becomes fibrous and thus loses its ability to function. These diseases, however, are not equally prevalent in the various groups of asbestos workers that have been studied: the amount and type of disease depend on the duration of exposure, the intensity of exposure, and particularly, the type or types of asbestos to which the individual has been exposed.

Lung cancer is caused by exposure to chrysotile, amosite, and crocidolite asbestos; however, increased risk of this disease is usually found only in those who also smoke. Asbestosis is caused by prolonged exposure to all forms of asbestos, whereas mesothelioma is principally caused by exposure to crocidolite asbestos. There is good evidence that chrysotile asbestos does not cause any significant amount of mesothelioma mortality, even after very heavy exposure. The common nonasbestiform amphibole minerals, cummingtonite, grunerite, tremolite, anthophyllite, and actinolite, which are often defined as "asbestos" for regulatory purposes, have not been shown to cause disease in miners.

Chrysotile asbestos, which accounts for about 95 percent of the asbestos used in the United States, has been shown by extensive Canadian studies to be safe when exposures do not exceed 1 fiber per cm^3 for the working lifetime. Chrysotile dust levels found in buildings rarely exceed 0.001 fibers per cm^3. Such dust concentrations will have no measurable health effect on the building occupants.

Present and future controls of minerals defined as "asbestos" and removal of asbestos from buildings and homes may cost many billions of dollars. Much of this expense is unnecessary and even counterproductive. Asbestos abatement could in fact produce a health risk to those exposed to dusts during and after removal operations. Overly restrictive controls could force the use of poor or dangerous substitutes, and could greatly affect the hard-rock mining industry.

INTRODUCTION

In our continuing search for new resources of industrial minerals and efforts for expanding their use, the possible health hazard related to exposure to mineral dusts has become an important factor in deciding which minerals can be safely mined, processed, and incorporated into commercial products.

A large number of experiments have been performed in which a variety of minerals and inorganic substances (such as fiber glass) have been implanted into the tissues of live animals. Often these animals developed cancer. These experiments strongly suggest that if ground up rock were similarly administered, a significant number of animals would develop tumors. The ability is at hand to "prove" that the Earth is a carcinogen!

The prevailing cancer dogma in the United States espouses the "no threshold" theory for cancer genesis. Influential health specialists have repeatedly said that because no one knows the minimum amount of a carcinogen required to initiate the growth of a cancer tumor, it must be assumed that <u>any amount of any carcinogen is unsafe</u>. The U.S. public has been led to believe that exposure to just one molecule of a chemical carcinogen can cause cancer. In regard to exposure to asbestos, this belief has become a paradigm to the effect that "one asbestos fiber can kill you."

Unless we decide that living on a carcinogenic earth is unacceptable and move elsewhere, a perception and an observation must be reconciled: (1) carcinogens produced by man, even in trace amounts, are responsible for most human cancer, and (2) carcinogens produced naturally are ubiquitous in our environment. The public has not been made aware that a large percentage of the carcinogens taken into the human body are naturally occurring chemicals found in foods, beverages, and tobacco. Examples of some of these carcinogens are <u>safrole</u>, <u>estragole</u>, and <u>methyleugenol</u> in edible plants; <u>piperine</u> in black pepper; <u>hydrazines</u> in edible mushrooms; <u>furocoumarins</u> in celery and parsnips; aflatoxins in corn, grain, nuts, cheese, peanut butter, bread and fruit; solanine and chaconine in potatoes; caffeic acid in coffee; theobromine in chocolate and tea; acetaldehyde, an oxidation product of ethyl alcohol, in alcoholic beverages; allyl isothiocyanate in mustard and horseradish; and nitrosamines formed from nitrates and nitrites found in beets, celery, lettuce, spinach, radishes, and rhubarb (Ames, 1983, 1984). The amount of these chemicals ingested by man is not trivial; for example, the common commercial mushroom *Agaricus bisporus* contains agaritine, a hydroxymethyl phenylhydrazine derivative, in a concentration of 3,000 parts per million or 45 mg per mushroom (Ames, 1984, p. 757)

In contrast to naturally occurring chemicals, man-made chemicals, which sometimes contaminate foods, air, and water, make up a relatively small portion of the total human intake of carcinogens. For example, Ames (1983, p. 1258) estimates that the human intake of naturally occurring pesticides (chemicals formed by plants themselves to fight insects, fungi, etc.) is at least 10,000 times greater than the human intake of man-made pesticides. Doll (1983) estimates that avoidance of tobacco smoke and alcoholic drinks would reduce cancer mortality by 38 percent, whereas avoidance of man-made carcinogens contaminating foods, air, and water would reduce cancer mortality by less than 1 percent.

The perception that small amounts of man-made chemicals are the major cause of human cancer mortality is blatantly false, as proven by a massive amount of epidemiological data and summarized by Doll and Peto (1981). Yet this perception, exemplified by statements such as "one fiber or molecule can kill you," is so strong in the minds of the U.S. public that it will take a massive effort by responsible scientists and journalists to change it. Bruce Ames, Sir Richard Doll, Richard Peto, John Higginson, John Cairns, Gio Gori, John Weisburger, Ernst Wynder, Edith Efron, and Michael Bennett are some who are leading the way in bringing good science and good journalism to the public's attention.

In the following sections, I will summarize the specialized topic "asbestos and health," but in context with the broader problem of human carcinogenesis and the public's perception of the causes of cancer. This summary is based on a long review paper published previously (Ross, 1984); for details and reference citations, the reader is referred to this publication.

As I will try to show, the asbestos problem is not restricted to the mining, milling, and use of commercial asbestos; it includes much of the mining industry, as well as the greatly expanding fiber and composites industry.

THE ASBESTOS PROBLEM

The widespread use of amphibole and serpentine asbestos by industrial society for uses such as brake and clutch facings, electrical and heat insulation, fireproofing materials, cement water pipe, tiles, filters, packings, and construction materials has contributed greatly to human safety and convenience. Yet, while our society was accruing these very tangible benefits, many asbestos workers were dying of asbestosis, lung cancer, and mesothelioma.

The hazards of certain forms of asbestos under certain conditions have been so great that several countries have taken extraordinary actions to greatly reduce or even ban their use. Recent experiments with animals demonstrate that the commercial asbestos minerals, as well as other fibrous materials, can cause tumors to form when the fibrous particles are implanted within the pleural tissue. These experiments have convinced some health specialists that asbestos-related diseases can be caused by many types of elongate particles: the mineral type, according to these health specialists, is not the important factor in the etiology of disease, but rather the size and shape of the particles that enter the human body.

At present, the most widely used definition of asbestos in the United States is taken from the notice of proposed rule-making for "Occupational Exposure to Asbestos," published in the Federal Register on Oct. 9, 1975 (p. 47652-47660) by the U.S. 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 crystallites or crystal fragments have the following dimensions: a length greater than 5 microns, a maximum diameter less than 5 microns, and a length-to-diameter ratio of three or greater. Any product containing any of these minerals in this size range is also defined as asbestos.

The crushing and milling of any rock usually produces some mineral particles that are within the size range specified in the OSHA rules. Thus, these regulations present a formidable problem to those analyzing for asbestos minerals in the multitude of materials and products in which they may be found in some amount. Not only must the size and shape of the asbestos particles be determined, but also an exact mineral identification must be made. A wide variety of amphiboles is found in many types of common rocks; many of these amphiboles might be considered asbestos depending upon the professional training of the person involved in their study and the methods used in mineral characterization.

If the definition of asbestos from the point of view of a health hazard does include the common nonfibrous forms of amphibole, particularly the hornblende and cummingtonite varieties, then we must recognize that asbestos is present in significant amounts in many types of igneous and metamorphic rocks covering perhaps 30 to 40 percent of the United States. Rocks within the serpentine belts; rocks within the metamorphic belts that are higher in grade than the greenschist facies, including amphibolites and many gneissic rocks; and amphibole-bearing igneous rocks such as diabase, basalt, trap rock, and granite would be considered asbestos bearing. Many iron formations and copper deposits would be asbestos bearing, including deposits in the largest open-pit mine in the world at Bingham, Utah. Asbestos regulations would thus pertain to many of our country's mining operations, including much of the construction industry and its quarrying operations for concrete aggregate, dimension stone, road metal, railroad ballast, riprap, and the like. The asbestos regulations would also pertain to the ceramic, paint, and cement industries, and to many other areas of endeavor where silicate minerals are used.

GEOLOGICAL OCCURRENCE OF COMMERCIAL ASBESTOS

Many minerals, including the amphiboles and some serpentines, are described variously as fibrous, asbestiform, acicular, filiform, or prismatic; these terms suggest an elongate habit. Although such minerals are extremely common, only in a relatively few places do they have physical and chemical properties that make them valuable as commercial asbestos. Locally, amphibole minerals may show an asbestiform habit, for example, in vein fillings and in areas of secondary alteration, but usually they do not appear in sufficient quantity to be profitably exploited.

Deposits of commercial asbestos are found in four types of rocks:

- (a) Type I - alpine-type ultramafic rocks, including ophiolites (chrysotile, anthophyllite, and tremolite);
- (b) Type II - stratiform ultramafic intrusions (chrysotile and tremolite);
- (c) Type III - serpentinized limestone (chrysotile); and
- (d) Type IV - banded ironstones (amosite and crocidolite).

Type I deposits are by far the most important and probably account for more than 85 percent of the asbestos ever mined. The most important Type I deposits are those in Quebec Province, Canada and in the Ural Mountains of the Soviet Union.

Type II deposits are found mostly in South Africa, Swaziland, and Zimbabwe; these furnish mostly chrysotile asbestos. Type III deposits are small; the most notable of these are located near Globe, Arizona and in the Carolina area of the Transvaal Province of South Africa. Type IV deposits are found only in Precambrian banded ironstones located in the Transvaal and Cape Provinces of South Africa and in Western Australia. Only the South African deposits are still in production. A complete review of the geological occurrences of commercial asbestos is given by Ross (1981).

Since the first recorded use of asbestos by Stone Age man, more than 100 million tonnes of asbestos have been mined throughout the world, of which more than 90 percent was chrysotile and more than 5 percent was crocidolite and amosite. Nearly 40 million tonnes of this total world production was chrysotile mined in Quebec Province near the towns of Thetford Mines and Asbestos. The total production of anthophyllite asbestos to date is probably no more than 400,000 tonnes, 350,000 tonnes being produced by Finland alone. The production of tremolite asbestos has been sporadic, and it has been mined in various parts of the world for short periods of time. The total production to date of this form of asbestos is probably no more than a few thousand tonnes. Commercial exploitation of actinolite asbestos is practically unknown.

The world asbestos production for 1981 was 4.34 million tonnes; the U.S.S.R. led with 48.5 percent and Canada was second with 25.9 percent of the world's output (Clifton, 1983). Both countries mine mostly chrysotile asbestos, and most of this comes from the Ural Mountains and Quebec Province.

THE NATURE OF ASBESTOS RELATED DISEASE

The three principal diseases related to asbestos are (1) lung cancer, (2) cancer of the pleural and peritoneal membranes (mesothelioma), and (3) asbestosis, a condition in which the lung tissue becomes fibrous and thus loses its ability to function. These diseases, however, are not equally prevalent in the various groups of asbestos workers that have been studied: the amount and type of disease depends on the duration of exposure, the intensity of exposure, and particularly, the type or types of asbestos to which the individual has been exposed.

Chrysotile or "White" Asbestos

Chrysotile asbestos, sometimes referred to in the trade as "white" asbestos, is the form that is usually used in the United States - as wall coatings, in brake linings, as pipe insulation, and in other uses. About 95 percent of the asbestos in in-place products in the United States is the chrysotile variety, and a large percentage of this was mined and milled in Quebec Province, Canada. Epidemiological studies of the chrysotile asbestos miners and millers of Quebec undertaken by medical researchers in Canada show that, for men exposed for more than 20 years to chrysotile dust averaging 20 fibers/cm^3, the total mortality (from all causes) was less than expected (620 observed deaths, 659 expected deaths). The risk of lung cancer was slightly increased: 48 deaths observed, 42 expected. Exposures to 20 fibers/cm^3 are an order of magnitude greater than those experienced now (which are 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. A similar mortality picture is reported for Italian chrysotile miners and millers.

Mesothelioma incidence among those working only with chrysotile asbestos is very low. Thus far, about 16 deaths due to this disease have been reported among chrysotile asbestos miners and millers and one among chrysotile trades workers. In addition, 6 deaths among sons and daughters of chrysotile miners and millers and 2 among others living in chrysotile asbestos-mining localities have been reported as being due to mesothelioma.

Four epidemiological studies of the female residents of the Quebec chrysotile-mining localities show no statistically significant evidence that their lifelong exposure to asbestos dust from the nearby mines and mills has caused excess disease.

Crocidolite or "Blue" Asbestos

Crocidolite, usually referred to in the trade as "blue" asbestos, was first imported into the United States in 1911 or 1912. By 1930, 35,000 short tons of crude blue fiber had entered the country, and by 1946, an additional 21,000 tons had been imported. In addition to these imports, much crocidolite has come into the United States as manufactured products, such as yarns, tapes, and pipe coverings. Almost all of the imported crocidolite has come from South Africa.

Epidemiological studies of groups that worked only with crocidolite asbestos show that rather short periods of exposure, or even relatively light exposure, cause excessive mortality due to lung cancer, mesothelioma, and asbestosis. This is evident not only in those exposed to crocidolite during gas-mask fabrication and building construction, but also in those employed in the crocidolite mines.

There are only two mining regions in the world where mesothelioma is a statistically significant cause of death. These are the crocidolite-mining districts of Cape Province, South Africa and of Wittenoom, Western Australia. Prevalence studies in Cape Province report that at least 278 persons have died of mesothelioma as a result of exposure to crocidolite; 161 of these persons worked in the mines and mills and 117 others lived near, the mines, but were not employed in the asbestos industry.

Thirty-one men who had worked in the small crocidolite industry (total production: 155,000 tonnes) at Wittenoom, Western Australia, have died of mesothelioma. Of these, 13 had worked for less than 12 months and 9 had had light to medium exposure to blue asbestos. Sixty miners and millers at Wittenoom have died of lung cancer; 34 of these men had worked in the industry for less than 12 months and 19 had had light to medium exposure to the crocidolite dust. In addition to this occupationally related mortality, 6 others who lived near, but did not work in, the mines or mills have died of mesothelioma.

Amosite or "Brown" Asbestos

All amosite asbestos comes from the Transvaal Province of South Africa, where approximately 2.2 million tonnes were mined between 1917 and 1979. Importation of amosite into the United States started in the 1930's.

Two complete epidemiological studies of asbestos trades workers exposed mainly to amosite asbestos have been published. The incidence of asbestos-associated disease in these two groups of men formerly employed at factories in London, England and Paterson, New Jersey was excessive, there being an 18.4 percent lung-cancer mortality (117 cases), 2.8 percent mesothelioma mortality (8 cases), and 4.2 percent asbestosis mortality (27 cases). Only prevalence studies have been made of amosite miners and millers; 2 individuals have died of mesothelioma. One resident of an amosite-mining district has been reported as having died of this disease.

The rock-forming amphibole minerals grunerite and cummingtonite, which are isostructural and chemically similar to amosite, are considered (incorrectly) by some to be forms of asbestos. Health studies of miners working ores that contain these minerals as gangue, for example, the Homestake gold mines and the Reserve iron-ore miners, do not show any indication of asbestos-related mortality.

Anthophyllite Asbestos

This form of asbestos has been mined sporadically in many localities, but the only major production has been at Paakkila, Finland, where approximately 350,000 tonnes was mined between 1918 and 1975. The only health study of individuals exposed predominantly to anthophyllite asbestos is that of the Paakkila miners. This group showed a 67% excess of lung cancer and a large mortality due to tuberculosis and asbestosis. There were no deaths from mesothelioma. Because anthophyllite was and is used so little in commerce, no additional health studies appear to be possible except for follow-up studies of the Paakkila miners.

DISCUSSION

The Relative Hazards of the Asbestos Minerals

Must the use of all commercial asbestos be stopped? The answer is an emphatic no, but with qualifications that are presented here.

Nonoccupational exposure to chrysotile asbestos, despite its wide dissemination in urban environments throughout the world, has not been shown by epidemiological studies to be a significant health hazard. If it were, the women of Thetford Mines and Asbestos, Quebec, where more than 40 million tonnes of chrysotile asbestos has been mined, would be dying of asbestos-related diseases. They are not. Health studies accomplished in Canada show that populations can safely breathe air and drink water that contains significant amounts of chrysotile fiber. These studies also suggest that there is a "threshold" value of chrysotile asbestos exposure below which no measurable health effects will occur.

The same fiber dose-disease response relationships observed for chrysotile asbestos do not hold for crocidolite asbestos. Health studies of those exposed to crocidolite show it to be much more hazardous than chrysotile. No study has been reported, comparable to that made for chrysotile, which would indicate what a safe level of exposure to crocidolite might be. The danger of crocidolite dust is particularly emphasized by the many mesothelioma deaths occurring among the residents of the crocidolite-mining districts of Cape Province, South Africa whose only exposure was in a nonoccupational setting. Such mortality is practically unknown among residents of the chrysotile-mining localities of Quebec Province.

The hazards of amosite asbestos are more difficult to assess. The amosite factory employees of London, England and Paterson, New Jersey, who generally worked under very dusty conditions, have experienced a great deal of excess mortality due to lung cancer, asbestosis, and mesothelioma. In contrast to these factory workers, amosite miners and millers, at least with regard to mesothelioma, do not appear to be at much risk.

The fear caused by alarmist statements such as "one fiber can kill you" and by the much exaggerated predictions of the amount of asbestos-related mortality expected in the next 20 or 30 years has generated great political pressure to remove asbestos from our environment and to reduce greatly 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, and so forth. This is being done, even though most asbestos in the United States is of the chrysotile variety and even though asbestos dust levels in schools, public buildings, and city streets are much lower than those found in chrysotile-mining communities, where little asbestos-related disease appears in the nonoccupationally exposed residents. The impetus for these costly removals and appliance recalls (hair dryers, for example) apparently comes from propagandizing of the "one-fiber-can-kill-you" concept. Not only is this program costly, but it could also be dangerous if the removal of blue 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.

Substitutes for Asbestos

If all use of asbestos were to be discontinued, substitutes would have to be developed to meet many diverse requirements for materials, such as nonflammability, high strength, flexibility, reasonable cost, and safety. With respect to safety, the substitutes must not induce disease in those exposed to them and also must not endanger lives in other ways by having inferior strength or durability, increased flammability, or other undesirable characteristics. A good substitute must not have so high a cost that it forces the use of an inadequate replacement. Possible problems can occur with substitutes, for example, with the replacement of chrysotile asbestos in drum-brake linings. The chance of increased automobile accidents due to a possibly inferior substitute material must be weighed against the probability of anyone being harmed by the small amounts of chrysotile asbestos emitted from drum brakes. The health effects of emissions from substitute brake linings must also be considered.

The requirements of strength and flexibility make it necessary that asbestos substitutes be fibrous. Generally, the thinner and longer the fibers, the stronger, more flexible, and useful they are; however, fibers longer than 4 microns and less than 1.5 microns in diameter are capable of producing malignant neoplasms when implanted into the pleura of rats. Test fibers used in these studies have included aluminum oxide, fiberglass, wollastonite, silicon carbide, dawsonite and potassium octatitanate.

Man-made Mineral Fibers

In addition to the very common exposure of man to naturally occurring fibrous minerals, he is also exposed to many different types of synthetically made fibers. More and more of these substances are being developed each year by the greatly expanding fiber and composites industries. Our knowledge of the health effects of most of these fibers is minuscule or nonexistent. The health effects of those exposed to man-made vitreous fibers, however, have been studied intensively and statistically significant studies are just now being reported. These glassy fibers, usually referred to as man-made mineral fibers (MMMF), include slag wool, rock wool, glass wool, fiberglass, and continuous-filament products. Two separate reports, one of 25,146 workers at 13 plants in Europe (Saracci and others, 1984), and one of 16,730 workers at 17 plants in the United States (Enterline and Marsh, 1985), have just been published or are about to be published. Table 1 gives a summary of the lung-cancer mortality for male workers in the European and United States MMMF industries who lived at least 30 years since first exposure. A statistically significant excess of lung cancer (52 percent) is seen in these MMMF workers. Exposure was generally less than 1 fiber per cm^3 and most commonly in the range of 0.01 to 0.1 fibers per cm^3. In contrast, the Quebec chrysotile asbestos miners and millers with at least 20 years service in the industry and exposed to between 10 and 21 fibers per cm^3 showed an excess of lung cancer of 12 percent. (Ross, 1984, p. 93).

Table 1. *Lung-cancer mortality, males, at least 30 Years observation since first employment in MMMF industry.*

		LUNG CANCER	
EUROPE (13 FACTORIES)	(Observed)	(Expected)	(Excess)
Rock wool	11	5.7	93%
Glass wool	4	2.6	54%
Continuous filament	2	0.6	233%
Subtotal	17	8.9	91%
UNITED STATES (17 FACTORIES)	(Observed)	(Expected)	(Excess)
Glass wool	47	36.0	31%
Slag wool	45	28.1	60%
Rock wool	14	8.1	73%
Subtotal	106	72.2	47%
TOTALS:	123	81.1	52%

Nonasbestiform Rock-Forming Amphiboles

Some health and regulatory specialists classify the common rock-forming amphiboles grunerite, cummingtonite, actinolite, tremolite, and anthophyllite as asbestos even though they do not possess the physical properties requisite to be valuable commercially. Such a classification has been made in the case of taconite mining by the courts (U.S. District Court for Minnesota, 380 F. Supp. 11) and by the U.S. Environmental Protection Agency (Reserve Mining vs. EPA, U.S. Court of Appeals Eighth Circuit, March 14, 1975). In the latter case, the U.S. Environmental Protection Agency (EPA) sued to prevent the Reserve Mining Co. from dumping taconite tailings into Lake Superior because of the perception that these tailings contain "amosite asbestos" and thus constitute a threat to public health. For a complete review of the case see 514 Federal Reporter, 2nd series, 492-542, 1975; and 256 Northwestern Reporter, 2nd series, 808-852, 1977.

The possible health effects of exposure to rock dust containing one or more of the many amphibole minerals is an important issue. Amphiboles are contained within the gangue (waste rock) of many hard-rock mines: gold, vermiculite, talc, iron ore, crushed stone and aggregate, copper, etc. Certainly control of most dust, regardless of the mineral content, is necessary because past heavy exposure to dusts containing crystalline silica (SiO_2), slate, coal, talc, and radioactive minerals have caused significant disease. Unusually tight control of amphibole-mineral particles, however, such as that proposed by the National Institute for Occupational Safety and Health (NIOSH) in 1976 for asbestos fibers (0.1 fibers per cm^3), could stop major mining in the United States.

Several epidemiological studies have been performed on hard-rock miners who were exposed to noncommercial amphibole dusts. One example is a cohort of gold miners at the Homestake Gold Mine, Lead, South Dakota, who were exposed to rock dust containing very significant amounts of amphibole belonging to the cummingtonite-grunerite series. The 861 observed deaths included 43 lung-cancer deaths (43 expected) and no mesothelioma deaths. Nonmalignant respiratory disease due to quartz dust, however, was excessive. This cohort thus showed no evidence of mortality that could be related to amphibole dust (David P. Brown and others, International Symposium, Chapel Hill, North Carolina, April 5, 1984, unpublished preprint). Studies of Reserve taconite (iron-ore) miners who were exposed to cummingtonite amphibole contained in the mine dusts also show no amphibole-related disease. Of the 298 deaths (344 expected), there were 15 lung-cancer deaths; 18 were expected. There were three excess deaths due to pneumoconiosis, perhaps due to quartz dust (Ross, 1984, p. 75). Despite no indication of asbestos-related disease in these miners, the Reserve Mining Company was required by the U.S. Courts (see above) to spend $300 million to build an inland dump site for waste rock.

COMMENTARY

The "no-threshold" cancer dogma that has been repeatedly foisted upon an unaware American public is generating a national crisis of such proportions that our economy could be very adversely affected. The economic consequences are particularly apparent in regard to the requirement by the Environmental Protection Agency that administrators report if asbestos is present in their schools. What is the school administrator to do when he is required by law to post signs in his school stating that asbestos is present? He has no option; he must have it removed because our cancer dogma translates the words on his building sign to "a little child breathing just one asbestos fiber may get mesothelioma 30 years later." The school administrator, the teachers, the parents, are in a box. The only way out of the box is to call for full ripout of the asbestos, even though well-informed experts know that many asbestos-removal programs, perhaps most, will put more fiber into the air than if it were left in place. Building owners, school systems, and local and State governments are suing many businesses for costs and damages related to asbestos removal, insurance companies are dropping liability coverage on workers removing asbestos, and occupants of buildings are suing over health effects or potential effects alleged to be caused by exposure to asbestos during renovation. The asbestos-removal workers themselves, I predict, will soon be suing their contractors because they too will believe that their health is threatened by exposure to asbestos.

What are we to do about asbestos substitutes that may also be carcinogenic in man — for example, the man-made mineral-fiber products such as rock wool and fiberglass? Since these products apparently cause excess lung cancer in long-term production workers, a logical and honest cancer policy would require that they also be removed from schools. Will the whole "asbestos-in-schools" scenario then be replayed, the main actor being fiberglass products rather than asbestos?

Fibers are not restricted to the school environment; many public and commercial buildings, churches, and private homes contain asbestos and the more modern fiberglass products. Are we to go through the asbestos-removal program for these structures as well? Where is the money to come from to cover the multibillion-dollar costs? How do we insure the workers? Is there any assurance at all that the occupants of the buildings undergoing asbestos ripout will not receive more exposure to fibers than if the material were left in place?

Lastly, what is to be done to control mineral dusts perceived to be asbestos or asbestoslike; for example, the rock-forming amphiboles that occur in most hard-rock mines? Will all mine- and mill-waste piles be considered toxic dumps? The challenge to the mining industry is here and it is serious.

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Comparison of Selected Zeolite Deposits of Arizona, New Mexico, and Texas

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ABSTRACT

Air-fall tuffs have been altered to zeolite via reaction of volcanic glass with local pore solutions at the six localities discussed in this paper. These are in the southern Basin and Range Province of Arizona and New Mexico, and in the Trans-Pecos and Coastal Plain regions of Texas. Zeolitization occurred in either closed-hydrologic, open-hydrologic, or hydrothermal groundwater systems.

The Dripping Spring Valley (DSV) chabazite in Arizona and the Buckhorn clinoptilolite in New Mexico originated in a late Cenozoic network of closed-hydrologic, lacustrine basins extending from southeast Arizona into southwest New Mexico. At DSV, two potentially commercial chabazite-rich tuffs are interbedded with lacustine mudstone. The main zeolite tuff contains up to 90 percent chabazite. The upper zeolite tuff averages approximately 67 precent chabazite. At the Buckhorn deposit, two clinoptilolite-rich tuffs are interbedded with lacustrine mudstone in the upper part of the Gila Conglomerate. The lower zeolite tuff contains up to 90 percent clinoptilolite. The upper zeolite tuff contains over 60 percent clinoptilolite.

The Casa Piedra clinoptilolite is in the Trans-Pecos region of Texas. It formed during the Tertiary in a closed basin containing a playa lake. The Casa Piedra tuff averages about 60 percent clinoptilolite.

Air-fall tuffs of the Cuchillo Negro, New Mexico and Tilden, Texas clinoptilolite deposits were zeolitically altered by either percolating ground waters in open-hydrologic systems or locally by ponded, saline, alkaline solutions. Cuchillo Negro tuffs are Tertiary and average approximately 50 percent clinoptilolite. Clinoptilolite-rich tuffs of Eocene age have been mined from four quarries at the Tilden deposits. Tuffs from the Kuykendall and Buck Martin quarries contain approximately 50 to 60 percent clinoptilolite.

Low temperature, SiO_2 - rich, hydrothermal solutions altered air-fall tuff to clinoptilolite and chabazite in the Foster Canyon area of the Tertiary Cedar Hills and Seldon Hills volcanic-vent zone in south-central New Mexico. Foster Canyon tuffs contain up to 60 percent zeolite and average 40 to 50 percent clinoptilolite.

The dominant mineral in the zeolite tuffs at the six deposits studied is generally microcrystalline and either chabazite or clinoptilolite. Lithic fragments, unaltered volcanic glass, other zeolites, quartz, calcite, opal-CT, cristobalite, feldspar, evaporites, clays, and mafic minerals are also constituents of the tuffs.

INTRODUCTION

Zeolite minerals occur in rocks of diverse lithology, age, and depositional environment. Zeolites are commonly the product of diagenetic reaction between volcanic glass and saline, alkaline pore solutions. Several genetic models of authigenic zeolite formation have been proposed (Hay, 1966, 1978; Sheppard, 1971, 1973; Munson and Sheppard, 1974). Deposit characteristics differ due to varying depositional and diagenetic conditions during zeolitization. We selected six zeolitic tuff deposits in Arizona, New Mexico, and Texas to describe and compare their geologic, petrologic, and mineralogic characteristics (Figure 1). These deposits formed in either closed-hydrologic, open-hydrologic, or hydrothermal groundwater systems.

The Dripping Spring Valley (DSV) chabazite in Arizona and the Buckhorn clinoptilolite in New Mexico formed in a late Cenozoic network of northwest-southeast-trending, closed basins extending from southeast Arizona into southwest New Mexico (Scarborough and Peirce, 1978). Air-fall tuffs at both deposits were zeolitized by reaction of vitric tuff with ponded, saline, alkaline-lake waters. The Casa Piedra, Texas clinoptilolite formed during the Tertiary in a closed basin by zeolite metasomatism of volcanic glass. The air-fall tuffs of the Cuchillo Negro (Tertiary), New Mexico and Tilden (Eocene), Texas clinoptilolite deposits were zeolitically

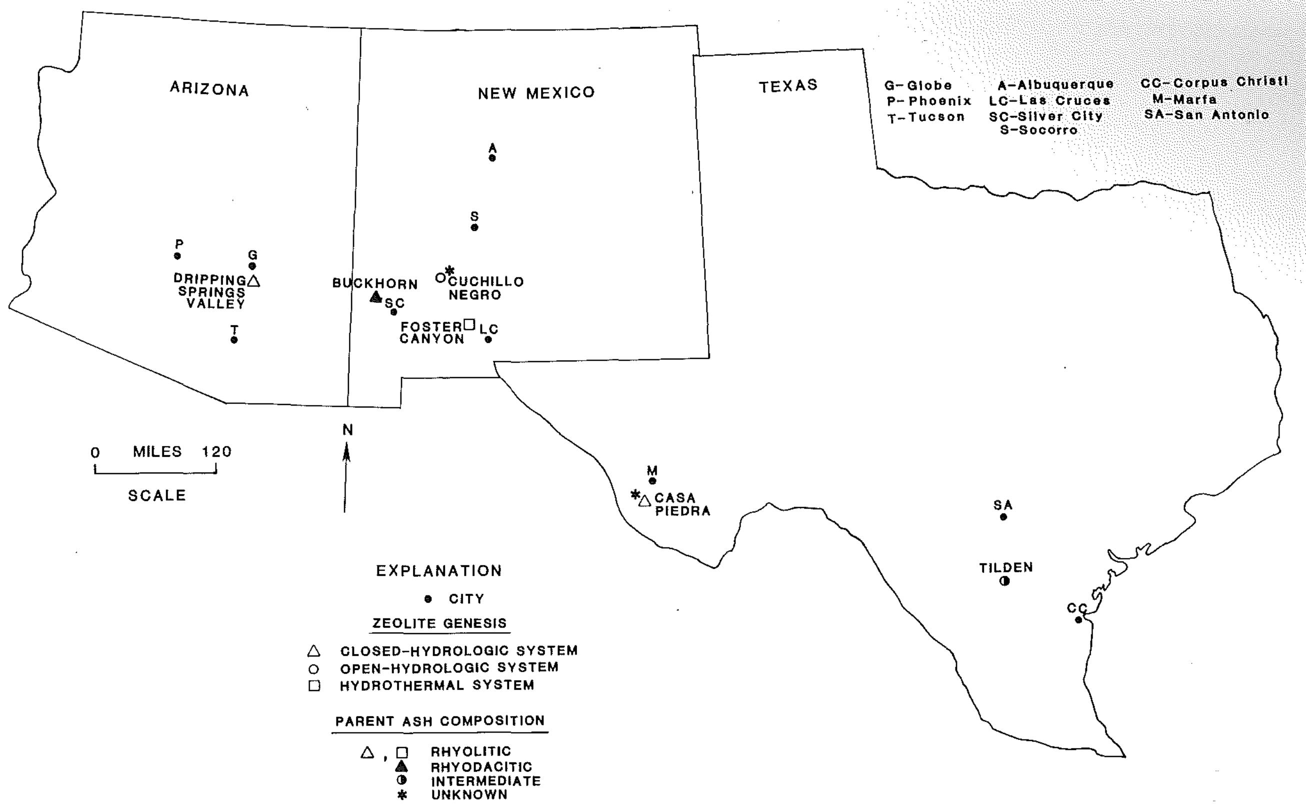


Figure 1. *Location of the six zeolite deposits discussed in this study. The deposits are keyed to their mode of zeolite authigenesis and parent-ash composition.*

altered in open-hydrologic systems. Hydrothermal solutions altered air-fall tuff to clinoptilolite and chabazite in the Foster Canyon area of the Cedar Hills and Selden Hills volcanic-vent zone (Tertiary) in south-central New Mexico.

The DSV deposit (Az. Dept. of Min. Res., 1978; Krieger, 1979; Eyde, 1982; Sheppard and Gude, 1982; Bowie, 1985) and the Buckhorn deposits (Olander, 1979; Eyde, 1982; Sheppard and Gude, 1982; Sheppard and Mumpton, 1984; Bowie, 1985) have been extensively studied. Walton and Groat (1972) briefly described the Casa Piedra and Tilden deposits of Texas. This paper is the first published account focusing on zeolitic tuff at Cuchillo Negro and Foster Canyon, New Mexico.

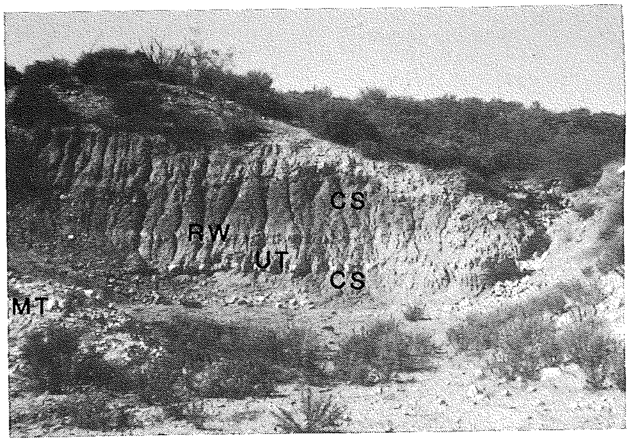
THE CHABAZITE DEPOSIT AT DRIPPING SPRING VALLEY, ARIZONA

The Dripping Spring Valley (DSV) chabazite deposit, about 23 miles south of Globe, Gila County, Arizona, is one of several late Cenozoic zeolite deposits formed in closed-hydrologic, shallow-lake basins in southeast Arizona and southwest New Mexico (Feth, 1964). It is a narrow, north-northwest-trending intermontane valley bounded by the Pinal (N), Mescal (NE), and Dripping Spring Mountains (SW).

Ten air-fall tuffs are known to be interbedded with more than 2,200 feet of Tertiary and Quaternary epiclastic fluviolacustrine deposits. Banks and Krieger (1977) tentatively correlate these deposits with the Big Dome Formation (early Miocene) in the Gila River Valley and the Quiburis Formation (Miocene or Pliocene) of the San Pedro Valley. At least five of the 10 tuffs were zeolitically altered, predominantly to chabazite. The altered tuffs also contain trace to abundant unaltered volcanic glass, quartz, calcite, dolomite, feldspar, evaporite minerals, mafic minerals, and clay minerals that are either detrital or authigenic.

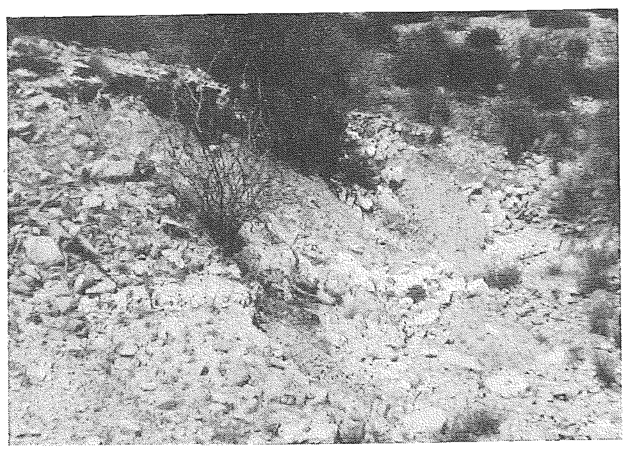
The Anaconda Minerals Company acquired the deposit in 1978. Anaconda drilled over 150 exploration holes targeting two zeolite tuffs, the main and upper horizons. They abandoned their claims in September, 1983.

The main zeolite tuff is stratigraphically the lowest tuff exposed (Figures 2 and 3). It underlies at least 1 square mile of basin-fill and ranges from 0.25 to 1.74 feet thick. The main zeolite tuff consists of three distinct lithologies: 1) a lower zeolitically altered ash, 0.15 to 0.87 feet thick, with about 10 percent detritus, 2) a middle zeolitically altered ash, 0.14 to 0.20 feet thick, which is laminated and thin-bedded, with traces of detritus, clay, and calcite, and 3) the



Source: Bowie, 1985.

Figure 2. *Southwest view of a prospect pit at the Dripping Spring Valley chabazite deposit. The white zeolite ore piled on the pit floor along the south side is from the main zeolite tuff (MT). A red lacustrine claystone (CS) is exposed at the base of the pit wall. It is overlain by the blocky, ledge-forming upper zeolite tuff (UT). A 1-foot-thick layer of white, reworked zeolitic sandy claystone (RW) is interbedded with lacustrine claystone about 1.5 feet above the upper zeolite tuff.*



Source: Bowie, 1985.

Figure 3. *View looking northwest at the main and upper zeolite tuffs interbedded with lacustrine claystone in the Dripping Spring Valley deposit. Hammer rests on the white, conchoidally fractured main zeolite tuff. A ledge of grayish-white upper zeolite tuff caps the hill. Blocks of upper zeolite tuff have slid down the hillside.*

stratigraphically highest and most massive bed, 0.30 to 0.67 feet thick, consisting of ash altered to zeolite (Eyde, 1982).

The main zeolite horizon was deposited on gently sloping alluvial-fan and playa-lake surfaces. Clay laminae deposited between the three ashes may have accumulated between separate ash-fall events. More likely, the laminae accumulated continuously and were punctuated by initial ash sedimentation and later reworking of the same ash. The lower ash bed of the zeolite horizon may represent ash initially deposited in the lake. The middle and upper ash beds probably are the same tuff originally deposited around the lake and later washed or blown into it. The main zeolite horizon contains infrequent sedimentary structures. These include ripple marks on laminae surfaces, soft-sediment deformation, and calcified root impressions. The sedimentary structures indicate partial reworking and disturbance of the lake bottom by currents and bioturbation.

Zeolitic alteration of the main zeolite tuff is heterogeneous. Sampling in 1960 indicates that the main tuff grades from clean, unaltered ash at the north end of the deposit to 90 percent chabazite at the south end (Eyde, 1982). X-ray diffraction (XRD) analysis of powder-press mounts of tuff by Anaconda returned from 0 to 69 percent chabazite (Bowie, 1985). The inverse relationship between the amount of chabazite and the amount of unaltered volcanic glass in the tuff suggests that the glass is altered to zeolite. Chabazite content generally increases basinward, where more saline, alkaline conditions were conducive to more complete zeolitization of the tuff. The unaltered glass content increases towards the lake margins. Freshwater influx is greater here so there is less zeolitization owing to lower pH and salinity.

Scanning electron microscopy (SEM) of the main zeolite tuff reveals chabazite and smectite $\pm$ mixed-layer illite/smectite pseudomorphic after volcanic glass (Figure 4).

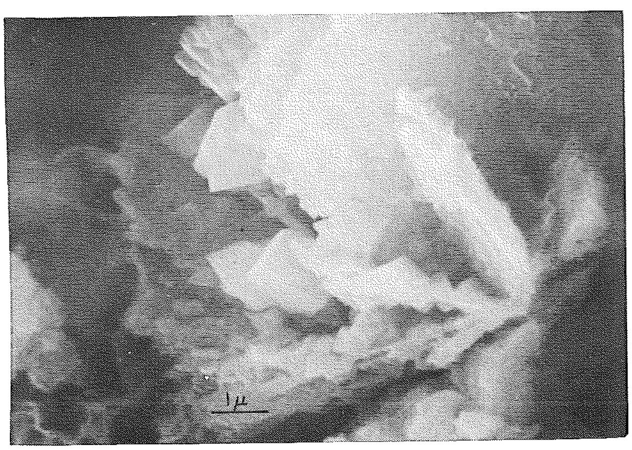


Figure 4. *Scanning electron micrograph of the massive bed of the main zeolite tuff from the Anaconda prospect pit. Leafy smectite and subhedral to euhedral chabazite cubes or rhombs form stacked, radial stringers up to 10 microns long on the volcanic glass substrate. Chabazite crystals appear also to have grown on smectite.*

Chabazite occurs as subhedral to euhedral cubes or rhombs varying from much less than 1 micron up to 2 microns on a side. The crystals are commonly intergrown forming either clusters or radial, fan-like stringers up to about 10 microns long. Smectite and mixed-layer illite/smectite occur as pore-filling and pore-lining, leaf-like, interconnected ridges much less than 1 micron wide and up to about 5 microns long. Chabazite is locally pseudomorphic after smectite (Figure 4).

The upper zeolite tuff averages approximately 67 percent chabazite. It is about 5 feet stratigraphically above the main zeolite tuff (Figures 2 and 3). The upper zeolite tuff averages about 1.5 feet thick, ranges up to 5.5 feet thick, and underlies over 3 square miles of basin-fill (Bowie, 1985). Three distinct lithologies with highly variable thickness and lateral continuity form the upper zeolite tuff: 1) a lower thin-bedded to platy bed, 2) an overlying massive bed, and 3) an upper thin-bedded to platy bed.

Seven silicic air-fill tuffs, the lowest of which lies about 150 feet stratigraphically above the upper zeolite tuff, underlie about 4 square miles of basin-fill at the north end of DSV (Bowie, 1985). The seven tuffs are interbedded with lacustrine mudstone, crop out over a vertical distance of about 60 feet, and average about 1.5 feet thick. The lower two are locally altered to chabazite. A "rhyolitic" tuff (Cornwall and Krieger, 1978) approximately 3 feet thick is stratigraphically the highest tuff exposed in DSV. It has been partly reworked and waterlain and is locally altered to chabazite.

Fluvial and lacustrine samples from DSV consist of discrete illite, mixed-layer illite/smectite, chlorite, smectite (mainly sodium montmorillonite), and kaolinite in decreasing order of abundance (Bowie, 1985). These relationships were determined by XRD from the <2 microns size fraction. The clay minerals are predominantly detrital. Some illite, smectite, and mixed-layer illite/smectite formed authigenically via reaction of precursor volcanic glass or clay minerals with the saline, alkaline water in the lake.

The air-fall tuffs of DSV are rhyolitic (Cornwall and Krieger, 1978; Krieger, 1979). X-ray florescence (XRF) spectrometry of DSV bulk zeolitic-tuff and unaltered tuff samples indicates that zeolitization of fresh rhyolitic ash produces an enrichment in Al_2O_3, MgO, CaO, and H

2O, and a loss of SiO_2 and K_2O (Krieger, 1979; Bowie, 1985). In some tuffs, Na_2O is enriched but it is depleted in others. Edson (1977) and Eyde (1982) report, for the Bowie chabazite deposit, a lateral chemical gradation of increasing CaO:Na_2O ratios in zeolitic tuff. They correlate this with increasing lake water salinity. The shallow, northwest end of the Bowie depositional basin was a calcium-rich, low-salinity environment characterized by calcite concretions within a high-grade zeolitic tuff. The deeper, southeast end of the Bowie basin was a sodium-rich, high-salinity environment characterized by the occurrence of high-sodium chabazite and thenardite within the same high-grade zeolitic tuff (Eyde, 1982). In contrast, at DSV, no such lateral gradation of CaO: Na_2O ratios is apparent from chemical analyses of the tuffs. Significant variation in lake water salinity is not apparent between the shallow, northwest end of the DSV basin and the deeper, southeast end. This relationship suggests that the deeper end at DSV was less saline than the deeper portion at the Bowie deposit. Lower salinity precluded formation of analcine at DSV; higher salinity favored it at Bowie.

SEM of DSV zeolitic tuffs reveals the paragenetic sequence of authigenic mineralization to be: unaltered volcanic glass ---> smectite $\pm$ mixed-layer illite/smectite, all overlapped by chabazite. Rare late-stage clinoptilolite and erionite probably crystallized at the expense of the earlier-formed smectite and chabazite. The complete basinward paragenetic sequence of unaltered volcanic glass ---> alkalic, silicic zeolites ---> analcine ---> potassium feldspar observed in many closed-hydrologic zeolite deposits (Sheppard and Gude, 1968; Hay, 1977; Surdam, 1977) probably did not develop in the DSV tuffs (Bowie, 1985). This partial development of the full paragenetic sequence is due to basinwide relatively low salinity and pH which allowed progression along the sequence only to clinoptilolite and erionite.

The DSV tuffs were altered mostly to chabazite. Chabazite precipitated when the hydrogen to alkali ion activity ratio decreased below the level for smectite crystallization. This precipitation followed dissolution of the rhyolitic volcanic glass in the tuffs by moderately saline and alkaline pore solutions shortly after deposition. Chabazite authigenesis was favored by the relatively silica-poor environment in which the activity of H_2O was high and the K to Na + Ca + Mg activity ratio was low (Bowie, 1985). Zeolitization of the fresh rhyolitic volcanic glass in the tuffs produces enrichment of Ca and Mg and loss of K_2O and SiO_2.

THE CLINOPTILOLITE DEPOSIT AT BUCKHORN, NEW MEXICO

The Buckhorn clinoptilolite deposit is in the Mangas Trench, a northwest-southeast-trending structural low, bounded by normal faults on the east and west. Clinoptilolite has been mined at Buckhorn from one of two zeolitic air-fall tuffs. These tuffs are exposed on the west side of Duck Green Valley in secs. 3, 4, and 10, T. 15 S., R. 18 W., about 1 mile south of Buckhorn, Grant County, New Mexico. The exploited tuff is visible to the west from U.S. Highway 180. Some potentially zeolitized tuffs crop out in the central and eastern portions of Duck Green Valley.

The zeolitized air-fall tuffs of the Buckhorn deposit are interbedded with the Pliocene-Pleistocene Cactus Flat beds of the upper part of the Gila Conglomerate (Heindl, 1958). Olander (1979) recognized four distinct depositional environments in the deposits: 1) soil which possibly developed along the edge of an alluvial fan, 2) intermittent stream-channel and adjacent overbank deposits, 3) interchannel, flood-plain deposits, 4) lacustrine or ponded deposits. The deposit is correlative with diatomite deposits, about 3 miles north of Buckhorn, that were placed at the boundary between early and middle Pliocene, an approximate age of 3 m.y. (Olander, 1979; Eyde, 1982). The U.S. Bureau of Mines explored, sampled, and tested the diatomite in the early 1940's. The results of the testing are unpublished but informal reports indicate the diatomite to be of good quality and at least 25 feet thick (Gillerman, 1964).

The two clinoptilolite-rich tuffs at the Buckhorn deposit are traceable for approximately 1 mile along strike. The tuffs are separated by about 20 feet of green and brown mudstone containing abundant smectite, zeolites, quartz, and calcite, and minor to trace illite, plagioclase, and secondary gypsum (Sheppard and Mumpton, 1984). Both zeolitic tuffs were probably originally rhyodacitic with a source in the Datil-Mogollon volcanic field (Olander, 1979).

The yellowish-white, massive, lower zeolite tuff is 3 to 5 feet thick and contains up to 70 to 90 percent clinoptilolite (Figure 5).

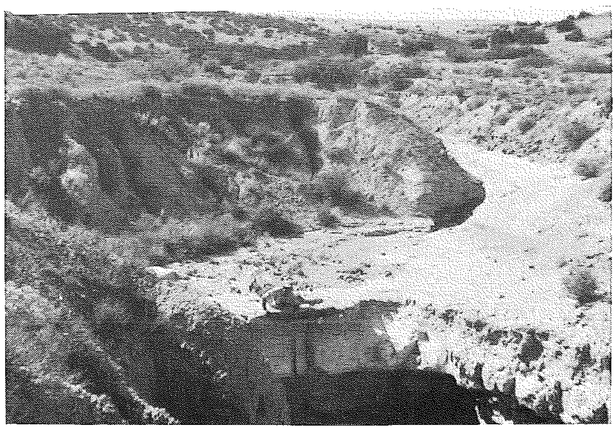


Figure 5. *At the Buckhorn clinoptilolite deposit, a resistant 4-foot-thick section of the lower zeolite tuff has influenced the formation of a 20 foot knickpoint in an ephemeral-stream arroyo.*

A lower layer in this tuff is 0.5 feet thick and contains about 48 percent clinoptilolite and about 48 percent chabazite (Eyde, 1982). The lower tuff also contains a clinoptilolite-heulandite intermediate phase, heulandite, analcine, magadiite chert, quartz, calcite, illite/smectite, plagioclase, flourite, hornblende, and biotite (Olander, 1979; Eyde, 1982; Sheppard and Mumpton, 1984). The upper zeolite tuff is massive, yellowish- to grayish-white, and is 1 feet thick. It contains over 60 percent clinoptilolite and a trace of erionite.

Lower tuff SEM reveals clinoptilolite pseudomorphic after volcanic glass and smectite (Figure 6). Clinoptilolite occurs as bushy clusters of coffin-shaped laths commonly radiating into voids. The crystals rarely exceed 3 microns in length and 2 microns in width. Smectite coats the volcanic glass shards and appears as wispy, interconnected ridges forming a honeycomb texture.

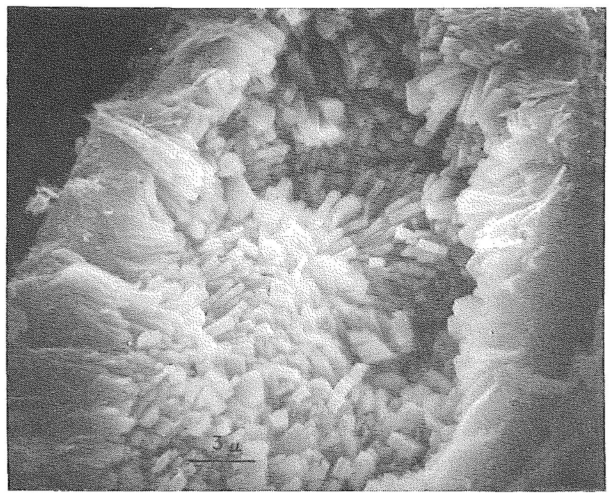


Figure 6. *Scanning electron micrograph from the lower horizon of the Buckhorn deposit. The paragenetic relationships between the volcanic glass, smectite, and clinoptilolite are clearly shown. Wispy smectite sparingly coats the volcanic glass grain. Clusters of coffin-shaped clinoptilolite laths radiate from the glass into a cavity.*

Interstitial solutions passing through the Buckhorn tuffs were saline and alkaline. The solution composition probably approached that of Lake Magadi, a $NaHCO_3$-CO_3 brine (Eugster, 1970), based on the occurrence of magadiite chert at Buckhorn. The solutions at Buckhorn were hypersaline and probably were moving basinward (Olander, 1979) during zeolitization. The chert precipitation suggests that the brine was unsuitable for forming zeolites with low Si to Al ratios, such as chabazite. Potassium feldspar formation was inhibited by the low K to Na + Ca + Mg activity ratio.

Tuff alteration initially formed minor smectite with overlapping heulandite-group mineralization, including clinoptilolite. Erionite and analcine precipitated later through reactions involving localized, highly saline, alkaline solutions. The two later zeolites locally replaced the earlier high-silicon zeolites.

Fluorite in a zeolitic tuff occurs about 2.5 miles east of Buckhorn. The fluorite is very small (<1 micron) and makes up 20 to 30 percent of the tuff. It occurs as pellets and ooids embedded in a matrix consisting predominantly of micrometer-size mordenite and smectite (Sheppard and Mumpton, 1984). The pellets and ooids probably are products of primary precipitation of fluorite and magadiite. They formed where dilute, calcium-bearing water from springs or streams mixed with fluorine-rich, saline, alkaline-lake water. The pellets are possibly biogenic and often form the cores of ooids. Both pellets and ooids were transported and reworked into the tuff prior to zeolitization (Sheppard and Mumpton, 1984).

THE CLINOPTILOLITE DEPOSIT AT CUCHILLO NEGRO, NEW MEXICO

The Cuchillo Negro clinoptilolite deposit is part of a thick, nonmarine Cenozoic sedimentary and volcanic section. This section occupies the southern end of the Winston Graben between the Black Range to the west and the Sierra Cuchillo to the east. The deposit is about 4 miles south of Winston, Sierra County, New Mexico.

Access to the deposit is via N.M. Highway 52 (paved), which intersects I-25 just north of Truth or Consequences. Follow Highway 52 northwest to Winston, then follow County Road 6 and USFS 157 (both improved dirt) south along the Chloride Creek drainage for approximately 4 miles. The central area of the deposit is at the junction of USFS 157 and the St. Cloud Mining Company's mill road. The St. Cloud Mill is 2 miles northwest of this intersection (Figure 7).

A Tertiary clinoptilolite tuff and conglomerate unit occurs within the Winston 7 1/2-minute quadrangle (Maxwell and Heyl, 1976). This unit is in secs. 34 and 35, T. 11 S., R. 8 W., and secs. 2, 3, 10, 11, 14, 15, 21, and 22, T. 12 S., R. 8 W. It is exposed for approximately 5 miles along a north-south trend (Figures 7 and 8) and crops out west and north of the confluence of South Fork Arroyo, Chloride Creek, and Cuchillo Negro Creek. The unit is displaced by several north-northwest-trending normal faults, and dips up to 60 degrees to the west-southwest.

The clinoptilolitic tuff and conglomerate is interbedded in a complex Tertiary volcanic and sedimentary section that is at least 2,500 feet thick in the Sierra Cuchillo. Individual units vary in form, thickness, lithology, and stratigraphic relationships. The volcanic rocks contain five depositional sequences (Jahns and others, 1978): early to middle Tertiary 1) upper andesite sequence, 2) rhyolite-trachyte sequence, 3) lower andesite sequence, 4) dacite-rhyodacite sequence, and early Tertiary 5) latite-andesite sequence. These five depositional sequences together contain many members, at least 12 of which are water-laid tuff. The water-laid tuffs may have been in part zeolitically altered by saline and alkaline pore water. Propylitically altered andesite (unit Tabt of Maxwell and Heyl, 1976) crops out throughout much of the central portion of the Winston quadrangle. Tabt contains a discontinuous, thick, green, fine- and coarse-grained, water-laid tuff near the top. This tuff may be altered in part to clinoptilolite.

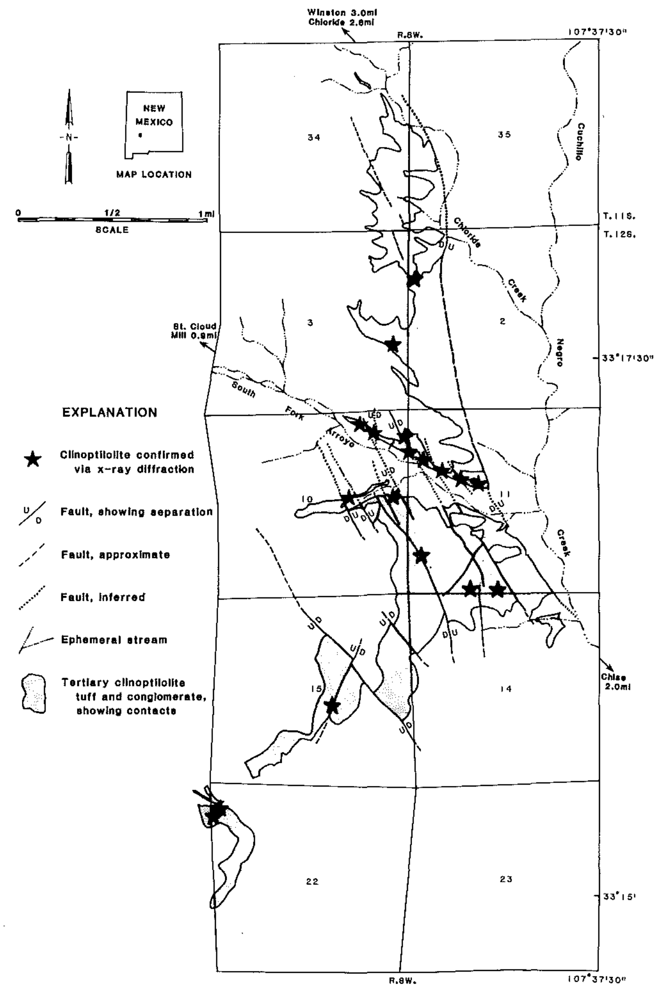


Figure 7. Tertiary clinoptilolite tuff and conglomerate at the Cuchillo Negro deposit. Starred sample localities contain clinoptilolite confirmed by XRD (modified from Maxwell and Heyl, 1976).

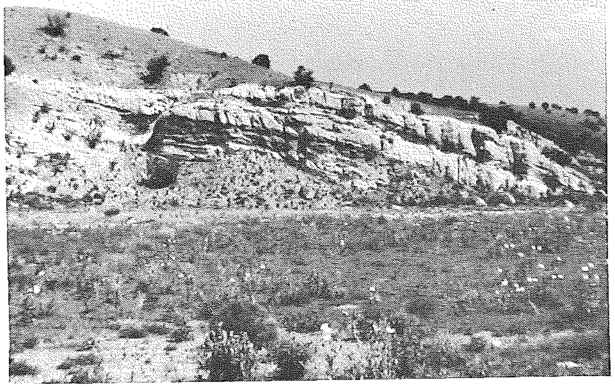


Figure 8. *Exposure of approximately 60 feet of faulted, steeply dipping, clinoptilolitic tuff along South Fork Arroyo at the Cuchillo Negro zeolite deposit. Telephone poles at base of the hill at far left and right center provide scale.*

The Tertiary volcanic rocks are unconformably underlain by the Lower Permian Abo and Bursum Formations, and the Upper Pennsylvanian Madera Limestone. The volcanic section is overlain by a thick sequence of Tertiary and Quaternary fine- and coarse-grained basin fill. The basin fill represents erosion of older rock units exposed in the nearby highlands. Jahns (1955) refers to the strata overlying the volcanics as the "Winston beds" and notes that they can be traced southward into the type section of "Palomas gravel". The sediments have also been divided into the "Rio Grande gravel", Gila Conglomerate, and Santa Fe Formation, but definitive correlations with other areas and sections have not yet been confirmed (Jahns and others, 1978). Jahns collected early Pleistocene vertebrates and fresh-water mollusks from the upper part of the Winston beds.

The clinoptilolitic sequence contains numerous zeolitically altered, light-buff to chalk-white tuffs interbedded with silty to sandy altered-tuff, sandstone, and conglomerate. Limited XRD analysis of powder-press mounts of this unit returned an average of approximately 50 percent clinoptilolite (Figure 7). Varying amounts of unaltered volcanic glass, quartz, calcite, feldspar, cristobalite, smectite, kaolinite, illite, and mixed-layer clay minerals also occur. Traces of chabazite, dolomite, pyrite, magnetite, biotite, and manganese minerals are present.

The paragenetic sequence of authigenic mineralization, based on SEM, is unaltered volcanic glass ---> early smectite ---> cristobalite(?) ---> clinoptilolite ---> late smectite (Figure 9). Smectite is pseudomorphic after the glass and occurs as leafy, interconnected ridges forming a honeycomb texture. Clinoptilolite formed from both volcanic glass and smectite. It occurs as subhedral to euhedral, coffin-shaped, monoclinic laths, either isolated or in clusters (Figure 9). The laths are up to 5 microns long and wide and up to 1 micron thick. Second generation smectite locally coats clinoptilolite.

Figure 9. *Scanning electron micrograph of clinoptilolitic tuff from the Cuchillo Negro zeolite deposit. Honeycomb smectite and coffin-shaped clinoptilolite laths have grown on a volcanic glass shard. Clinoptilolite has also displacively overgrown smectite.*

The tuffs in the Cuchillo Negro deposit were apparently zeolitically altered by groundwater in an open-hydrologic system. The groundwater chemistry was modified by hydrolysis and dissolution of the vitric tuff. The zeolitization cuts across stratigraphic boundaries, a characteristic of alteration in open-hydrologic systems. However, local zeolitization by ponded, saline, alkaline solutions cannot be ruled out.

THE CLINOPTILOLITE DEPOSIT AT FOSTER CANYON, NEW MEXICO

The Foster Canyon clinoptilolite deposit lies primarily in the easternmost half of T. 21 S., R. 2 W., and in the westernmost sections of T. 21 S., R. 1 W. It is about 16 miles northwest of Las Cruces, and is near Radium Springs, Dona Ana County, New Mexico. Several zeolitically altered air-fall tuffs are exposed in the Foster Canyon collapse area of the Tertiary Cedar Hills and Selden Hills volcanic-vent zone (Seager and Clemons, 1975).

The deposit can be reached by taking Exit 19 (Interstate 25), proceeding west to U.S. Highway 85, and turning right (north). Continue through Radium Springs and turn left (west) onto the upper dirt road just south of mile marker 17. Drive 3.3 miles west then turn right (north) off the ridge onto a jeep trail and proceed 2.6 miles until reaching the Leonard Minerals Company prospect pit, located in the SE1/4 SW1/4 NW1/4 sec. 14, T. 21 S., R. 2 W. The deposit is in the Corralitos Ranch 7 1/2-minute quadrangle mapped by Clemons (1976).

In the Cedar Hills and Selden Hills vent zone, the Tertiary section includes the Eocene Palm Park Formation, the Oligocene Bell Top Formation, and the Miocene to Pliocene(?) Rincon Valley Formation (Seager and others, 1971; Seager and Clemons, 1975). The Palm Park Formation consists of about 2,000 feet of epiclastic, laharic, andesitic detritus. Other facies present in the Palm Park include fluvial, basin-floor, and piedmont-slope (toe), and subvolcanic sills, dikes, and minor flows (Seager and Clemons, 1975). The Palm Park Formation is unconformably overlain by the Bell Top Formation. The Bell Top in the vent zone can be subdivided into four units: 1) lower tuffs and breccia, 2) ash-flow tuff, 3) upper air-fall and epiclastic deposits, and 4) flowbanded rhyolite domes and flows (Seager and Clemons, 1975). Porous to dense crystal-vitric ash-flow tuff and muddy to sandy conglomerate interfinger with tuffaceous sedimentary members.

In Foster Canyon, up to 800 feet of white to tan, rhyolitic air-fall tuff, breccia, and interbedded epiclastic pebbly sandstone were deposited as moat-fill after vent-clearing, explosive eruptions (Figure 10). Clemons (1976) refers to these deposits as the upper tuffaceous sedimentary member. The lower parts of the member contain clasts of Paleozoic limestone, Palm Park Formation, ash-flow tuff, and vesicular andesite. Ash, cross-bedded epiclastic sediment, and pumiceous, vitrophyre tuffs dominate the upper parts (Seager and Clemons, 1975). Basaltic andesite either formed dikes and plugs intruding the member or formed interbedded flows.

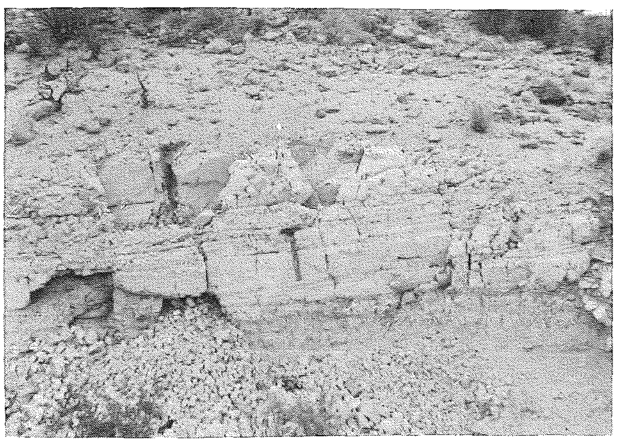


Figure 10. *Bedded, reworked air-fall tuff in the Cedar Hills and Selden Hills vent zone exposed at the Foster Canyon clinoptilolite deposit. It contains approximately 50 percent clinoptilolite with subordinate lithic fragments, unaltered volcanic glass, smectite, and feldspar. Hammer is for scale.*

The Tertiary volcanic and igneous section is separated from the fanglomerate facies of the overlying Rincon Valley Formation by an angular unconformity. An angular unconformity also separates the Rincon Valley Formation from the overlying piedmont-slope facies of the Pleistocene Camp Rice Formation. Late Pleistocene to Holocene arroyo, fan, and the terrace, as well as minor playa deposits and eolian sand, unconformably overlie the Camp Rice.

The dominant structural feature of the Foster Canyon deposit is the north-northeast-trending, late Tertiary Cedar Hills normal fault. This and subsidiary late Tertiary high-angle normal faults are superimposed across the Goodsight-Cedar Hills depression, a broad, shallow, volcano-tectonic sag of Oligocene age (Seager, 1973). Uplift and erosion along these faults exposed the volcanic-fill of the depression, as well as the strata and structure of the Cedar Hills vent zone along the eastern margin of the depression (Seager and Clemons, 1975). These volcano-tectonic features are precursors to the Rio Grande rifting (Seager and Clemons, 1975).

The upper tuffaceous sedimentary member is extensively zeolitized and locally opalized. Several siliceous or fused-tuff structures are conspicuous at the surface as resistant, sinuous, crosscutting ridges with up to 3 feet of relief above the surrounding surface. The fused-tuffs are cemented by opal-CT, suggesting a relatively low-temperature (<65 degrees C) alteration event (McGrath, 1985). The tuffs were probably silicified as SiO_2-rich hydrothermal solutions moved up along fractures. They are now prominent owing to differential erosion.

McGrath (1985) collected samples at 1-foot intervals for 20 feet along a traverse of three fused-tuff ridges in the upper tuffaceous sedimentary member. In addition to opal-CT, XRD analysis detected smectite and clinoptilolite. The relative abundances of smectite and clinoptilolite are inversely proportional to their distance from the fused-tuff ridges. Clinoptilolite is more concentrated at the ridges and smectite is more concentrated away from them. This relationship supports a hydrothermal origin for at least some of the zeolite. Other zeolite may be post hydrothermal. The clinoptilolite is unstable in the modern soil (McGrath, 1985).

Clinoptilolite was detected in secs. 14 and 25, T. 21 S., R. 2 W., and along the boundary of secs. 19 and 30, T. 21 S., R. 1 W. Chabazite was found to be the dominant zeolite in several samples from the west-central part of sec. 14, T. 21 S., R. 2 W., but is generally much less abundant then clinoptilolite. Analcime occurs rarely in the west-central part of section 14 (McGrath, 1985). Zeotech Corporation analyzed several samples by XRD from sec. 2, T. 20 S., R. 2 W., secs. 11, 13, 14, and 25, T. 21 S., R. 2 W., and sec. 19, T. 21 S., R. 1 W.; all are nonzeolitic.

Zeotech Corporation augered over 300 holes into the Foster Canyon deposit and analyzed tuffaceous samples by XRD. The tuffs contain up to 60 percent zeolite, and average 40 to 50 percent clinoptilolite. Reserves are tentatively estimated at 200,000 to 300,000 short tons of 50 percent clinoptilolite. Exact reserve calculations are difficult to make because of the irregular gradation between zeolitized and nonzeolitized tuff and the intermixing of siliceous, fused-tuff zones with zeolitic tuff.

In addition to zeolites, opal-CT and smectite, the tuffs contain lithic fragments ranging in composition from basalt to rhyolite, varying amounts of unaltered volcanic glass, and minor quartz, calcite, biotite, kaolinite, sanidine, K-feldspar, and albite. The zeolitic tuff is generally massive and structureless. Local cross-bedding is present probably due to the tuffs having been reworked by fluvial processes (Figure 10).

The paragenetic sequence of authigenic mineralization, determined with SEM and in thin section, is unaltered volcanic glass ---> early smectite --> clinoptilolite, opal-CT ---> late smectite (Figure 11). Honeycomb smectite coats glass and clinoptilolite. Opal-CT occurs as clusters or stringers of subrounded balls up to 5 microns in diameter. The paragenetic relationship between opal-CT and clinoptilolite is unclear, but they apparently coexist. Clinoptilolite occurs as subhedral to euhedral, coffin-shaped laths that are commonly intergrown and chaotically arranged. The laths are abou arranged. The laths are about 20 to 30 microns long, up to 10 microns wide, and up to 5 microns thick.

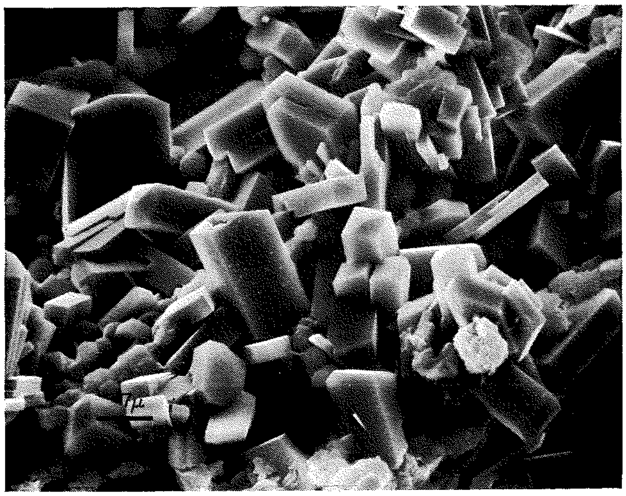


Figure 11. Scanning electron micrograph of zeolitic tuff at the Foster Canyon clinoptilolite deposit. Chaotic and commonly intergrown, coffin-shaped clinoptilolite laths are intermixed with clusters or stringers of subrounded balls of opal-CT.

THE CLINOPTILOLITE DEPOSIT AT CASA PIEDRA, TEXAS

The Casa Piedra clinoptilolite deposit is in Presidio Co., Texas, about 1 mile northeast of Casa Piedra and about 40 miles south of Marfa. A clinoptilolite-rich tuff crops out in the lower part of the Tertiary Tascotal Formation. The Tascotal crops out almost continuously from approximately 6 miles south of Marfa to nearly the Rio Grande south of the Bofecillos Mountains. North of Casa Piedra, the Tascotal crops out in low hills and cuestas. Clinoptilolite is a minor constituent in the matrix of high-energy fluvial sandstones along this outcrop line but is locally concentrated in an air-fall tuff interbedded with low-energy lacustrine rocks. Walton and Groat (1972) collected nearly pure clinoptilolite samples just north and northeast of Casa Piedra.

The Casa Piedra deposit contains a white, air-fall tuff 1 to 5 feet thick and averaging about 60 percent clinoptilolite (Figure 12).

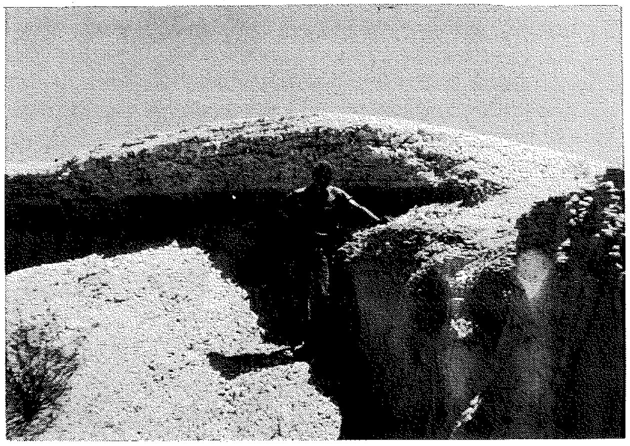


Figure 12. Clinoptilolite-rich tuff overlying lacustrine mudstone in the Tertiary Tascotal Formation at the Casa Piedra zeolite deposit. This tuff is 1 to 5 feet thick and contains approximately 60 percent clinoptilolite and minor unaltered volcanic glass, cristobalite, feldspar, and biotite.

The tuff also contains unaltered volcanic glass, and minor biotite, smectite, feldspar, and cristobalite. The paragenetic sequence of authigenic mineralization, based on SEM, is unaltered volcanic glass---> early smectite ---> clinoptilolite ---> late smectite (Figure 13). Fuzzy, honeycomb smectite has grown from

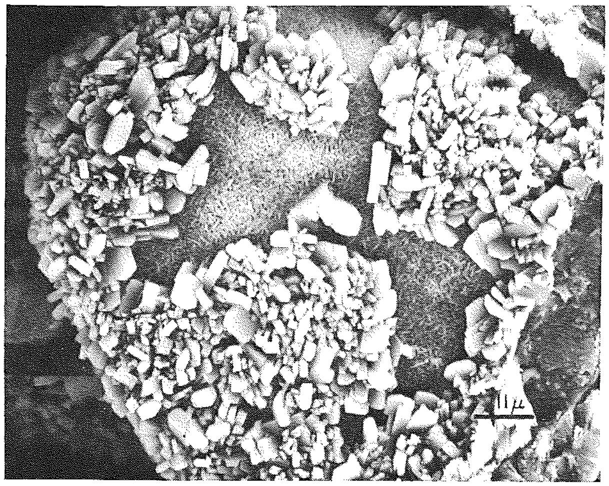


Figure 13. *Scanning electron micrograph of clinoptilolite-rich tuff from the Casa Piedra zeolite deposit. The etched volcanic glass shard (right center) is coated with honeycomb smectite. Patches of coffin-shaped clinoptilolite laths have grown from the smectite and volcanic glass.*

an etched volcanic-glass substance and locally coats clinoptilolite. Clinoptilolite crystallized from a volcanic-glass precursor and from smectite. It occurs as isolated laths or as clusters of subhedral to euhedral, coffin-shaped laths often lining vugs and radiating into voids. The clinoptilolite laths are up to 7 microns long, 5 microns wide, and up to 3 microns thick.

The tuff was altered to zeolite by reaction of volcanic glass with saline, alkaline-pore solutions in a closed-hydrologic system, probably a playa lake and peripheral environment. The tuff overlies brown, sandy mudstone and has worm and clam burrows at the base. It crops out in circular fashion over approximately 1 square mile. The deposit also contains tuffaceous sandstones laid down in high-energy fluvial systems. The central portion of the deposit was largely eroded prior to paleochannel formation. Reserves are about 100,000 short tons of material averaging 60 percent clinoptilolite.

THE CLINOPTILOLITE DEPOSITS AT TILDEN, TEXAS

The Tilden clinoptilolite deposits are near the town of Tilden, McMullen County, Texas; approximately 80 miles south of San Antonio and 100 miles northwest of Corpus Christi. To date, clinoptilolite is the only potentially commercial zeolite found in south Texas. Clinoptilolite-bearing tuffs have been mined from four quarries, named after the property owners: 1) Kuykendall, 2) Buck Martin, 3) Henry Martin, and 4) Dilworth. The Kuykendall and Buck Martin quarries are about 8 miles west, the Dilworth quarry about 8 miles southwest, and the Henry Martin quarry about 1 mile southeast of Tilden. The deposits occur in the Eocene Manning Formation of the Jackson Group within Gulf Coast stratigraphy. "The Jackson Group is an extensive series of strike-oriented sand units which comprise the south Texas strandplain-barrier bar system. The sands grade updip and downdip into predominantly mud systems, the south Texas lagoonal-coastal plain and the shelf systems, respectively" (Walton and Groat, 1972).

The zeolitized air-fall tuffs were originally deposited in quiet lagoons behind barrier islands, and/or in associated coastal-fluvial and washover- fan environments (Walton and Groat, 1972).

The zeolitized air-fall tuffs were originally deposited in quiet lagoons behind barrier islands, and/or in associated coastal fluvial and washover fan environments (Walton and Groat, 1972). The source of the tuff may have been northern Mexico (B. Donegan, pers. comm., 1984). Zeolitization probably occurred in open-hydrologic systems where meteoric waters reacted with vitric tuff. Local alteration in ponded saline, alkaline waters (closed-hydrologic) is also possible.

The clinoptilolite-rich tuffs are white, gray, or various pastel shades and are more resistant to erosion than adjacent beds. They form massive, blocky, or flaggy ledges with subconchoidal to conchoidal fracture. They are up to 3 feet thick (Walton and Groat, 1972) and each ledge consists of individual beds ranging in thickness from 1 to 3 inches. Ledges are laterally persistent except where erosion, dominantly in paleo-channels, has removed the tuffs. Some tuffs are structureless, some are laminated, and some display small-scale foreset or trough crossbeds. Climbing ripples characterize some highly zeolitized units (Walton and Groat, 1972). XRD analyses indicate that in addition to abundant clinoptilolite, the tuffs contain varying amounts of unaltered volcanic glass, montmorillonite, opal-CT, sodic plagioclase, and quartz (Walton and Groat, 1972).

Kuykendall Pits

The three Kuykendall pits trend northeast-southwest over approximately 10 acres. They contain clinoptilolite-rich tuffs 6 to 12 feet thick (Figure 14). "The tuffs are thickest in the center of the trend, grade laterally into muddy, tuffaceous units to the west, and disappear into the subsurface to the north and east" (Walton and Groat, 1972).

The Kuykendall tuffs overlie a buff to blue-green, well indurated, silicified sandstone with local clay-size detrital matrix or clay interbeds. A light-gray to reddish-brown, locally tuffaceous clay with silty and

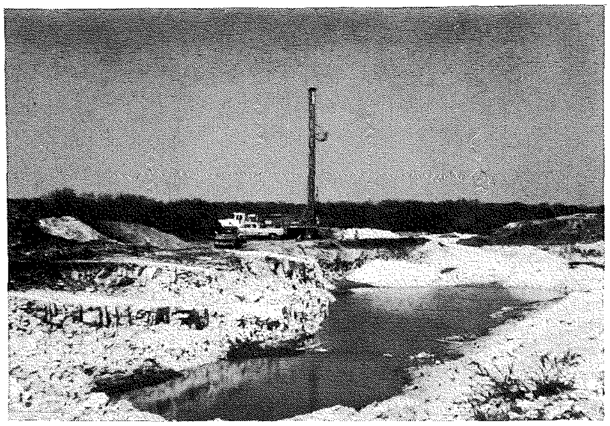


Figure 14. *Drill rig at the end of one of the three Kuykendall pits near Tilden, Texas. Note the blocky nature of the zeolite ore. The McMullen Co. Highway Dept. hauled rock from this and other nearby zeolite quarries for road-fill. The streets of Tilden and many county roads are constructed from this material. The zeolite ore compacts well, does not get slippery when wet, and is hard enough to resist breakdown under heavy traffic.*

sandy interbeds, overlies the tuffs. Unconsolidated sand and gravel locally overlie or truncate this sequence. A black to reddish-brown soil, generally less than 3 feet thick, caps the whole sequence. A uniformly thick (4 feet) lignite bed underlies the sedimentary sequence and is an excellent basal marker horizon throughout the deposit.

Tuffs at Kuykendall are white, gray, or pale yellow above the groundwater table (GWT) and are reduced and bluish-gray below it. The tuffs are locally very hard and, in places, are clayey, silty, and sandy. Climbing ripples and small-scale festoon and trough cross-beds are common, but locally the beds are thin-bedded (1 to 5 inches) and structureless. Manganese and iron oxide staining defines some bedding planes (Figure 15).

Analysis by XRD indicates that the Kuykendall tuffs contain approximately 50 to 60 percent clinoptilolite, 30 percent montmorillonite, and up to 20 percent opal-CT. Minor unaltered volcanic glass and iron and manganese oxides are also present. Zeotech Corporation estimates reserves at over 700,000 short tons of adsorbent clinoptilolite (50 to 60 percent) on its leases covering over 2,300 acres.

The paragenetic sequence of authigenic mineralization, from SEM, is unaltered volcanic glass---> early smectite ---> clinoptilolite ---> late smectite (Figure 16). Smectite occurs as porelining, honeycomb masses coating volcanic glass and clinoptilolite. Clinoptilolite occurs as vug-filling, subhedral to euhedral, coffin-shaped laths. Typical crystals are about 5 microns long and 3 microns wide ranging locally up to 17 microns long and up to 10 microns wide. Pore solutions have partially dissolved some clinoptilolite and have induced a second generation of smectite precipitation.

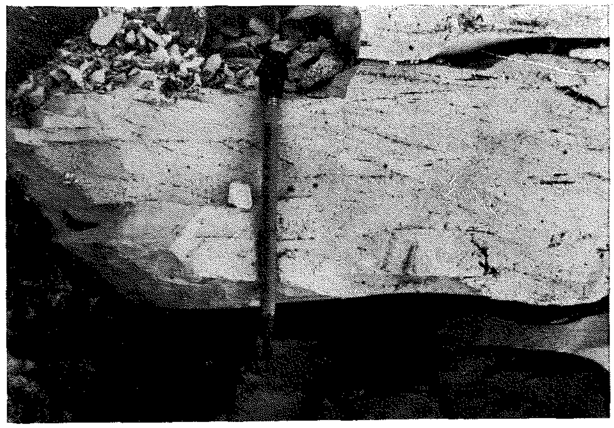


Figure 15. *Stratified and cross-bedded clinoptilolite-rich tuff at one of the Kuykendall pits. Manganese and iron oxides define bedding planes. Dark iron oxide blebs are pseudomorphic after pyrite.*

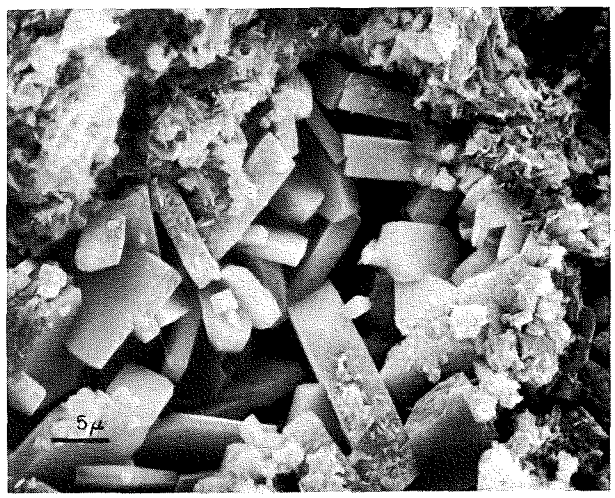


Figure 16. *Scanning electron micrograph of clinoptilolite-rich tuff from one of the Kuykendall pits. Wispy, pore-lining smectite coats volcanic glass. Coffin-shaped clinoptilolite laths have grown from the volcanic glass and smectite into the void. The clinoptilolite has been partially etched and is locally replaced by smectite.*

Buck Martin Quarry

The Buck Martin quarry is nearly circular and covers about 8 acres. Quarry faces expose up to 8 feet of clinoptilolite-rich tuffs on the northeast wall; they disappear in the southeast portion of the quarry (Figure 17).

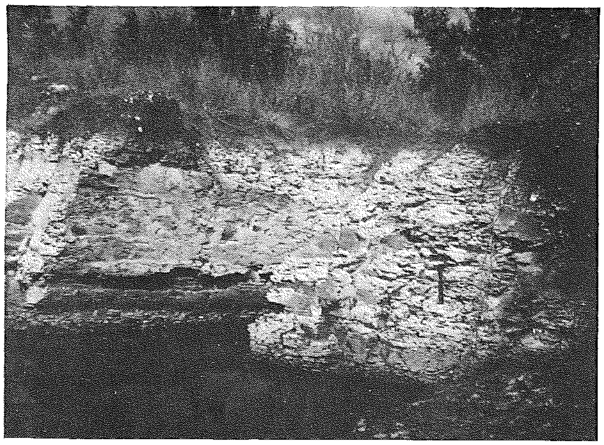


Figure 17. *Clinoptilolite-rich tuff exposed in the Buck Martin road metal quarry. The pit walls have been recontoured since this photograph was taken in 1981. Note the cross bedding and flagging fracture in the ore. Geologic hammer is for scale.*

The tuffs contain approximately 50 percent clinoptilolite, 30 percent montmorillonite, and up to 20 percent opal-CT. The clinoptilolite-rich tuffs are flaggy and contain columnar jointing, crossbedding, and climbing ripples. A sandstone with abundant mud clasts underlies the tuffs. Smectitic clay 3 feet thick overlies the tuffs in the northeast section of the quarry; 2 feet of black soil overlies them in the north-west and central potions. Overburden thickness increases southward as the tuffs thin (Walton and Groat, 1972).

Henry Martin Quarry

The Henry Martin quarry is kidney-shaped and is 5 feet deep over 1 acre. At the quarry, clinoptilolite-rich tuffs break along bedding or parting planes 4 to 10 inches. thick. No underlying beds are exposed, but a sandstone unit adjacent to the quarry apparently dips under the tuffs (Walton and Groat, 1972). The lateral extent of the tuffs is unknown. Overburden consists of 1 foot of smectitic, clayey soil. Vegetative cover is extensive.

Dilworth Quarry

The Dilworth quarry has an areal extent of about 4.5 acres and up to 6 feet of relief (Walton and Groat, 1972). The thickness and lateral extent of the clinoptilolite-rich tuffs are unknown because of lack of exposures. The flaggy tuffs break along partings 1 inch thick. The Dilworth deposit has no overburden. To the south, the tuffs disappear under burrowed, smectitic clay, which grades vertically into an overlying burrowed, tuffaceous sandstone (Walton and Groat, 1972).

MINERALOGIC COMPARISON OF THE DEPOSITS

Table 1 lists the genetic classification and some mineralogic characteristics of the six zeolite deposits studied. Clinoptilolite is the dominant zeolite at each deposit except DSV, where chabazite is dominant. Chabazite is also dominant in the zeolitic tuffs of the nearby closed-hydrologic zeolite deposits at Bear Springs and Bowie in southeast Arizona. An apparent regional trend of zeolite authigenesis from abundant chabazite mineralization in the southeast Arizona zeolite deposits to predominant clinoptilolite mineralization in the New Mexico and Texas zeolite deposits is probably not real. The precipitation of a particular species of zeolite is more likely dictated by local diagenetic conditions, pore-solution chemistry, and parent-ash composition.

The zeolites of all six deposits are microcrystalline, but those formed in the closed-hydrologic systems at DSV, Buckhorn, and Casa Piedra are generally finer-grained than those formed in the open-hydrologic or hydrothermal systems at Cuchillo Negro, Tilden, and Foster Canyon (Table 1). The zeolites in the closed-hydrologic systems may be finer-grained because they had more distal ash sources so the particles deposited in them were smaller. Relatively small pores were available for crystal growth after fine-sediment compaction in the subaqueous environment. Relatively large pores were available for large clinoptilolite crystal growth in the coarser, poorly sorted and poorly bedded Foster Canyon tuffs.

The paragenetic sequence of authigenic mineralization at each deposit is quite similar, except that the deposits exhibit varying stages of authigenesis (Table 1). The DSV tuffs were altered mostly to chabazite by moderately saline and alkaline lake waters. These waters were relatively SiO_2-poor, had a high activity of H_2O, and had a low K to Na + Ca + Mg activity ratio, chemical conditions that inhibit the crystallization of high-silicon zeolites such as clinoptilolite, and low-water zeolites such as analcime. These conditions persisted throughout the period of zeolitization at DSV.

The pore solutions that altered the Buckhorn tuffs were more saline and alkaline than those that altered the DSV tuffs. At Buckhorn, alteration of the tuffs resulted in minor smectite with overlapping heulandite-group (including clinoptilolite) mineralization. Erionite and analcime precipitated when localized, concentrated, saline and alkaline solutions reacted with the earlier, high-silicon zeolites.

There is a common paragenesis of unaltered volcanic glass ---> early smectite ---> clinoptilolite ---> late smectite at the Cuchillo Negro, Foster Canyon, Casa Piedra, and Tilden

Table 1. *Genetic classification and some mineralogic characteristics of the six zeolite deposits discussed in this paper. Grain size was determined by SEM and refers to the dominant zeolite phase.*

Deposit	Parent-ash composition	Dominant genetic system	Dominant and (subordinate) zeolite phases[1]	Typical grain size	Paragenesis of authigenic mineralization[1,2]
Dripping Springs Valley	rhyolitic	closed-hydrologic	Cb (Cl, Er)	≤ 1 μ square	Gl —> Sm(I/Sm), Cb
Buckhorn	rhyodacitic	closed-hydrologic	Cl (He, Cb, Er, An, Mo)	≤ 3 μ long	Gl —> Sm —> Cl, He —> Er, An —> Mag —> An
Cuchillo Negro	unknown	open-hydrologic	Cl (Cb)	≤ 5 μ long	Gl —> Sm —> Cb, Crist, Cl —> Sm
Foster Canyon	rhyolitic	hydrothermal	Cl (Cb, An)	≤ 15 μ long	Gl —> Sm —> Cl, Opal-CT —> Sm
Casa Piedra	unknown	closed-hydrologic	Cl	≤ 7 μ long	Gl —> Sm —> Cl —> Sm
Tilden	intermediate	open-hydrologic	Cl	≤ 5 μ long	Gl —> Sm —> Cl —> Sm

[1] Cb = chabazite, Cl = clinoptilolite, Er = erionite, He = heulandite, An = analcime, Mo = mordenite
[2] Gl = unaltered volcanic glass, Sm = smectite, I/Sm = mixed-layer illite/smectite, Mag = magadiite, Crist = cristobalite

deposits. Local, differing diagenetic conditions produced slight variations in progression along the sequence, such as chabazite precipitation at Cuchillo Negro and Foster Canyon and opal-CT cementation at Foster Canyon and Tilden. The possible paragenetic sequences of authigenic mineralization of closed-hydrologic, open-hydrologic, and hydrothermal systems are quite diverse (Surdam, 1977; Hay and Sheppard, 1977; Boles, 1977). Only slight variations in mineral assemblages occur amongst the four zeolite deposits listed above. The assemblages probably formed under similar conditions of parent-ash composition, pore- solution chemistry, and diagenesis.

In addition to zeolite, the tuffs analyzed contain varying amounts of impurities, including unaltered volcanic glass, clay minerals, quartz, opal-CT, calcite, feldspar, and biotite. Although these analyses may resemble analyses of the constituent zeolites, they are in fact analyses of rocks. Several compositional characteristics of the zeolitic tuffs are apparent.

Table 2. *Major-oxide chemical analyses as determined by X-ray fluorescence spectrometry of bulk zeolitic tuff samples from each of the zeolite deposits discussed in this report. Results reported in weight percent oxide. LOI determined at 900°C (3) and 1000°C (1), others unknown.*

Oxide \ Deposit / Ore / tuff	DSV Cb main	DSV Cb upper	DSV Cb main	DSV Cb ?	Buckhorn Cl† lower	Buckhorn Cl lower	Cuchillo Negro Cl ?	Foster Canyon Cl† ?	Casa Piedra Cl	Casa Piedra Cl†	Tilden Cl† ?	Tilden Cl ?
SiO_2	54.17	53.2	54.10	53.1	56.6	63.40	64.72	~68	67.70	68.0	68.4	73.90
Al_2O_3	15.29	14.8	15.04	14.7	12.1	12.20	12.65	12.3	13.10	12.3	12.1	11.50
Fe_2O_3 (FeOx)	2.09	1.6	1.57	1.88	(1.3)	1.33	≤3.72**	(1.5)	1.63	(1.5)	(0.8)	0.92
MgO	2.80	2.8	2.12	2.70	1.4	1.70	1.04	0.8	0.60	0.5	0.7	0.84
CaO	2.50	2.1	2.40	3.40	2.7	3.37	3.32	1.0	1.69	2.7	2.4	1.52
Na_2O	2.18	4.4	3.48	3.50	0.8	1.40	0.88	2.0	3.70	2.1	0.6	1.30
K_2O	1.96	1.2	1.89	1.50	1.1	1.12	3.31	3.7	2.04	3.0	1.7	0.59
TiO_2	0.37	0.06	0.33	0.32	—	0.13	0.24	—	0.26	—	—	0.22
P_2O_5	0.06	0.08	0.05	<0.10	—	<0.10	0.04	—	0.10	—	—	<0.10
MnO	0.02	0.03	0.02	<0.02	—	<0.02	0.05	—	<0.02	—	—	<0.02
H_2O^+	—	9.4	—	—	3-5 (b) 5-10 (f)	—	—	3-6 (b) 4-10 (f)	—	3-5 (b) 5-10 (f)	4-7 (b)	—
H_2O^-	0.91	9.6	0.02	—	—	—	2.81	—	—	—	—	—
LOI*	18.79	9.47	18.44	18.40	—	15.06	8.77	—	8.89	—	—	8.84
TOTAL	101.14	99.34	99.46	99.50	—	99.71	—	—	99.71	—	—	99.63
$SiO_2O:Al_2O_3$	3.54	3.59	3.60	3.61	4.68	5.20	5.12	~5.53	5.17	5.53	5.65	6.43
Impurities	glass, quartz, calcite, feld., clays	trace quartz, feld., clay	glass, quartz, calcite, feld., clays	mo., trace quartz, trace clays	trace clays	trace clays	?	glass, vrf	?	glass, biotite, feld.	minor glass, smectite, opal-CT	opal-CT, clays
Reference	1	4	1	3	2	3	2	2	3	2	2	3

References: 1) Bowie (1985); 2) Zeotech Corp. files (unpubl.); 3) Sheppard and Gude (1982); 4) Krieger (1979).
Note: DSV = Dripping Springs Valley; Cb = chabazite, Cl = clinoptilolite; mo. = mordenite; vrf = volcanic rock fragments; *LOI = H_2O^+ + CO_2; ** includes 1.84% Fe_2O_3 and ≤1.88% FeOx; b = bound H_2O^+; f = free H_2O^+; † = Analyses of zeolite products--Turflite (Tilden), Clinolite 10 (Foster Canyon), Clinolite 15 (Casa Piedra), and Clinolite 20 (Buckhorn) as marketed by Zeotech Corp., Albuquerque, NM.

Ideal chabazite has a Si:Al ratio of 2.0; chabazite from sedimentary environments is more silicon-rich and has a Si:Al ratio ranging from 3.0-4.1 (Sheppard and Gude, 1975). The SiO_2:Al_2O_3 ratio of the four DSV chabazite-rich tuff samples ranges from 3.54 to 3.61. Two of the four DSV samples show a predominance of alkaline-earths; the other two are alkali-rich and sodic (Table 2).

The composition of natural clinoptilolite is extremely variable. Clinoptilolite is more silicon-rich and has a higher Si:Al ratio than chabazite. The Si:Al ratio of clinoptilolite ranges from 2.7 to 5.0 and clinoptilolite ranges from completely calcic to dominantly alkalic (Hay, 1966). There is a general increase in the SiO_2:Al_2O_3 ratio of the clinoptilolite-rich tuffs analyzed eastward from the low of 4.68 at Buckhorn. The ratio is 5.12 at Cuchillo Negro, 5.53 at Foster Canyon, 5.17 and 5.53 at Casa Piedra, and reaches highs of 5.65 and 6.43 at Tilden (Table 2). The increase in the ratio from New Mexico to Texas is probably coincidental when all variables, such as regional tectonics, parent-ash composition, and local pore-solution chemistry are considered.

Sheppard and Gude (1982) report major-oxide chemical analyses for 16 clinoptilolite-rich tuffs of the western United States, including samples from Buckhorn, Casa Piedra, and Tilden (Table 2). Only two of 16 samples, including Buckhorn, show a predominance of alkaline-earth elements; the remainder show a predominance of alkalis. Three of the five clinoptilolite-rich tuffs we analyzed show a predominance of alkaline-earths and are calcic (Table 2). The Foster Canyon and Casa Piedra tuffs are alkalic. The Foster Canyon sample and one of the Casa Piedra samples is potassic. The other Casa Piedra sample is sodic.

CONCLUSIONS

Geologic, petrologic, and mineralogic characteristics of zeolitic tuffs were compared between six zeolite deposits in Arizona, New Mexico, and Texas. The major conclusions reached in this study are:

1. The Dripping Spring Valley (DSV) chabazite and Buckhorn clinoptilolite deposits are two of several late Cenozoic zeolite deposits formed in closed-hydrologic, lacustrine basins in southeast Arizona and southwest New Mexico. The Casa Piedra, Texas clinoptilolite also formed during the Tertiary in a closed basin containing a playa lake.
2. Air-fall tuffs of the Cuchillo Negro, New Mexico and Tilden, Texas clinoptilolite deposits were zeolitically altered by either percolating groundwaters in open-hydrologic systems or by ponded, saline, alkaline solutions. The tuffs at Tilden were deposited in quiet lagoons behind barrier islands, and/or in associated coastal fluvial and washover fan environments.
3. Air-fall tuff was zeolitically altered by low-temperature, SiO_2-rich, hydrothermal solutions in the Foster Canyon area of the Tertiary Cedar Hills and Selden Hills volcanic-vent zone in south-central New Mexico.
4. The dominant mineral of the zeolitic tuffs at the six deposits is generally microcrystalline chabazite or clinoptilolite. Typical impurities or associated minerals include: lithic fragments, unaltered volcanic glass, other zeolites, quartz, calcite, opal-CT, cristobalite, feldspar, evaporites, clays, and mafic minerals. The deposits exhibit varying stages of authigenic mineralization. A general paragenetic sequence of unaltered volcanic glass ---> early smectite and/or mixed layer illite/smectite ---> chabazite or clinoptilolite ---> analcine, erionite ---> late-stage smectite is indicated by SEM and thin section analyses. Variations in this sequence were dictated by local diagenetic conditions, pore-solution chemistry, and parent-ash composition.
5. There are two potentially commercial, chabazite-rich tuffs in DSV. The main zeolite tuff underlies about 1 square mile of basin fill, is 0.25 to 1.74 feet thick, and contains up to 90 percent chabazite. The upper zeolite tuff underlies over 3 square miles of basin fill, averages 1.5 feet thick, and contains approximately 67 percent chabazite.
6. At the Buckhorn deposit, two clinoptilolite-rich tuffs, separated by about 20 feet of lacustrine mudstone, crop out for about 1 mile along strike on the west side of Duck Creek Valley. The lower zeolite tuff is 3 to 5 feet thick and contains up to 90 percent clinoptilolite. The upper zeolite tuff is 1-foot thick and contains over 60 percent clinoptilolite. The potential for commercial development is currently being assessed.
7. Cuchillo Negro tuffs average approximately 50 percent clinoptilolite. The potential reserve base appears to be large but is untested.
8. Foster Canyon tuffs contain up to 60 percent zeolite and average 40 to 50 percent clinoptilolite. Reserves are tentatively estimated at 200,000 to 300,000 short tons of material averaging 50 percent clinoptilolite.

9. The Casa Piedra tuff is 1 to 5 feet thick and averages about 60 percent clinoptilolite. Reserves are estimated at 100,000 short tons of material averaging 60 percent clinoptilolite. No commercial development has occurred.
10. Clinoptilolite-rich tuffs have been mined from four quarries at the Tilden deposits. The three Kuykendall pits cover approximately 10 acres. They contain zeolitic tuffs 6 to 12 feet thick containing approximately 50 to 60 percent clinoptilolite, 30 percent montmorillonite, and up to 20 percent opal-CT. The Buck Martin quarry covers about 8 acres. Quarry faces expose up to 8 feet of zeolitic tuffs with composition similar to those in the Kuykendall pits. The Henry Martin quarry is 5 feet deep and covers about 1 acre. The Dilworth quarry is up to 6 feet deep and covers about 4.5 acres. The lateral extent of clinoptilolite-rich tuffs exposed in latter two quarries is unknown.
11. The $SiO_2:Al_2O_3$ ratio of four DSV chabazite-rich tuff samples ranges from 3.54 to 3.61. A general increase occurs in the $SiO_2:Al_2O_3$ ratio of clinoptilolite-rich tuffs eastward from the low of 4.68 at the Buckhorn deposit to the high of 6.43 at the Tilden deposit; the $SiO_2:Al_2O_3$ trend is probably coincidental. The $SiO_2:Al_2O_3$ ratio of the tuffs is probably dictated more by local diagenetic conditions, pore-solution chemistry, and parent-ash composition than by a west-to-east change in magma source composition or tectonic influence.

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Geology and Industrial Uses of Arizona's Volcanic Rocks

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ABSTRACT

Volcanic activity occurred during six periods of Arizona's geologic history. Precambrian volcanism occurred in two pulses at 1.8-1.6 billion years (b.y.) ago and at 1.2-1.1 b.y. ago. Volcanism occurred again in mid-Jurassic and Laramide (Late Cretaceous-early Tertiary) time. Volcanic rocks from these times are not used commercially in any significant quantity. Middle and late Cenozoic magmatic activity covered large areas of Arizona with voluminous volcanic rocks. During the mid-Tertiary magmatic pulse, explosive silicic magmatism, with eruption of areally extensive ash-flow tuffs, covered large areas in the Basin and Range Province, while the Colorado Plateau remained largely unaffected. Basalt eruption also occurred during and immediately after silicic volcanism, leading to compositionally diverse suites of volcanic rocks. Late Cenozoic volcanism occurred throughout Arizona and was dominated by widespread eruption of basalt flows with local cinder-cone clusters and siliceous volcanic deposits.

Perlite deposits near Picketpost Mountain in northeastern Pinal County account for the bulk of the industrial uses of mid-Cenozoic volcanic rocks. Other perlites of presumed middle Tertiary age are present in central, southeastern, and western Arizona, but to date remain unexploited. Arizona Fire Agate is a valuable gem material and is associated with volcanic rocks of middle Tertiary age. Basaltic rock of this age also is utilized in the manufacture of rock wool for insulation.

Late Cenozoic volcanism produced most of the industrial-quality volcanic rocks. Basalt, cinder cones, and materials of rhyolitic composition are commercially exploited by municipal and Federal agencies and private industry for aggregates, road conditioners and maintenance materials, asphaltic concretes, cinder block construction, pozzolans, and landscaping. These deposits are generally confined to the Flagstaff and Springerville areas. A famous peridot gem locality is associated with late Tertiary basalts at Peridot Mesa on the San Carlos Indian Reservation. Important products derived from altered volcanic materials of late Cenozoic age include clay and zeolite.

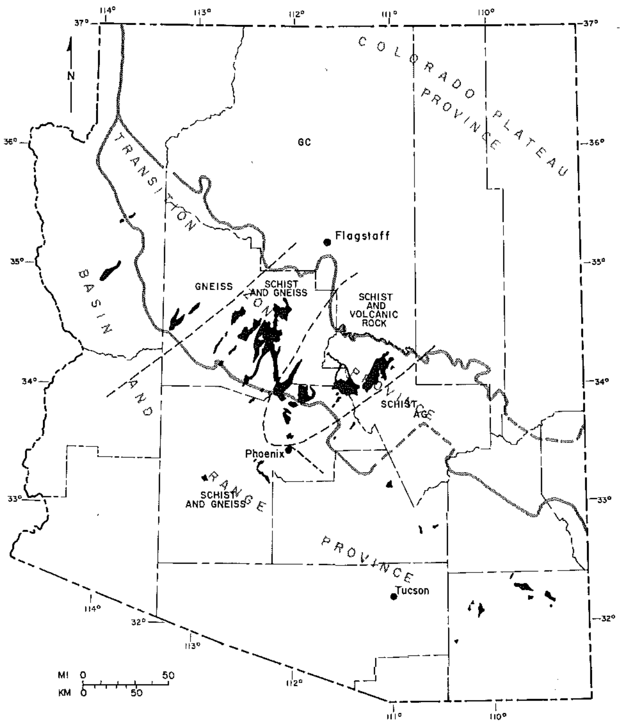
Arizona's volcanic-rock sequences are still incompletely known, particularly in central and western Arizona. The potential for recognition and exploitation of important new deposits of useful volcanic materials is high.

INTRODUCTION

Six episodes of volcanism are recognized in the geologic history of Arizona. These episodes have unequally affected all three of Arizona's geologic-physiographic provinces: Colorado Plateau, Transition Zone, and Basin and Range Province (Peirce, 1984). Volcanism in these terranes has produced a diversity of volcanic rocks some of which have utilitarian uses. In many cases geographic distribution has determined their usefulness.

The earliest volcanic episode in Arizona occurred during the Proterozoic between 1.8 and 1.6 b.y. ago, and was one of the processes that resulted in formation of the continental crust that underlies the State. Volcanic rocks formed during this time are most widely exposed in the Transition Zone and parts of the Basin and Range Province (Figure 1). Proterozoic volcanic rocks are products of two distinct generations of volcanism that together are characteristic of Precambrian "greenstone belts" in many other parts of the world. The older part involves a primitive bimodal suite of tholeiitic basalt and rhyodacite that was built upon a mafic basement of oceanic character (Anderson, 1986). This activity was followed by a period of submarine calc-alkaline mafic volcanism, which was succeeded by submarine to subaerial alkali-calcic felsic volcanism (Anderson, 1986). A second episode of Proterozoic volcanism occurred about 1.2 to 1.1 b.y. ago, but was more areally restricted and less voluminous than the previous episode. This younger period of volcanism is represented by basalt flows and rhyolite tuff interbedded with sedimentary rocks of the Apache Group near Globe and the Unkar Group of the Grand Canyon (Figure 1).

In the early Mesozoic, volcanic activity is first evidenced by volcanic ash and detritus deposited in the Upper Triassic Chinle Formation (Colorado Plateau) from eruptive centers to the south and west (Peirce, 1986). By Jurassic time, volcanism was widespread in



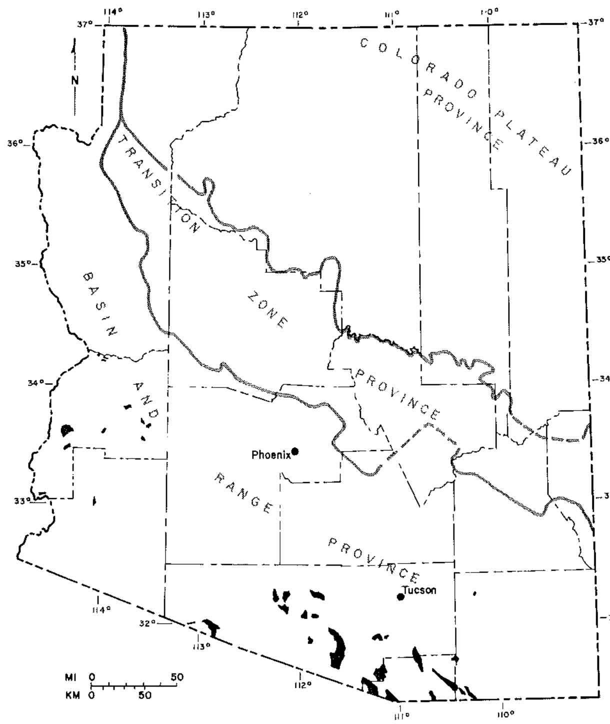


Figure 1. *Outcrops of metamorphosed Precambrian volcanic rocks formed during the first (1.8-1.6 b.y.) episode are shown in black. Outcrops of rocks formed during the second episode (1.2-1.1 b.y.) are too small to show individually, but occur in the Unkar Group in the Grand Canyon area (GC) and the Apache Group near Globe (AG) as interbeds. Geology from Anderson (1986).*

Figure 2. *Outcrops of Jurassic volcanic rocks. Modified from S. J. Reynolds (written communication, 1986).*

a northwest-trending belt that traversed Arizona from Douglas to Parker (Figure 2). Jurassic volcanic rocks are composed of dacitic to rhyolitic ash-flow tuffs, air-fall tuffs, flows, and flow breccias; andesitic volcanics are less common.

During Laramide (Late Cretaceous to early Tertiary) time another belt of magmatism appeared and migrated eastward across Arizona. Volcanic rocks of this age are most widely preserved in southeastern Arizona (Figure 3). This volcanic episode resulted in the construction of andesitic stratavolcanoes and andesitic to rhyolitic caldera complexes. Remnants of these calderas are present in the Silver Bell, Tucson, and Santa Rita Mountains outside Tucson (Lipman and Sawyer, 1985).

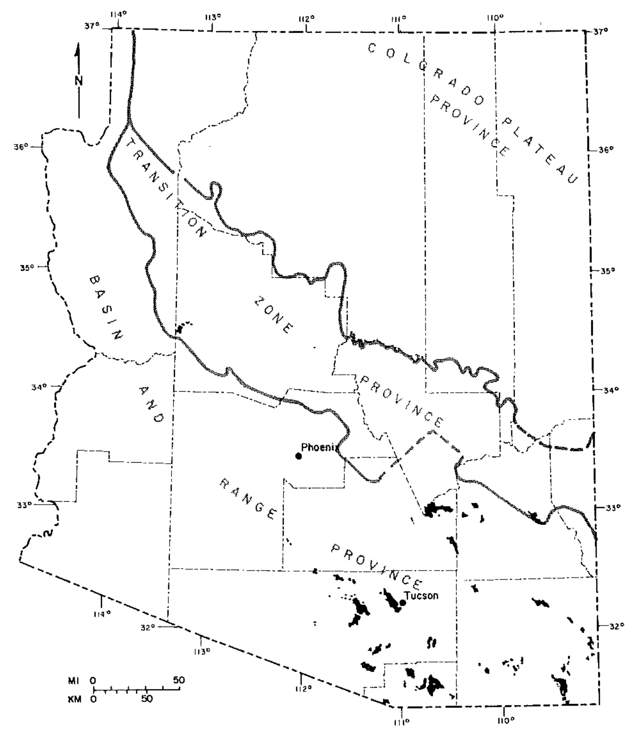


Figure 3. *Outcrops of Late Cretaceous to early Tertiary (Laramide) volcanic rocks. Modified from Keith (1984).*

Middle and late Cenozoic magmatic activity occurred over large areas of Arizona and produced voluminous quantities of volcanic rocks. During the mid-Tertiary magmatic pulse (Figure 4) explosive silicic magmatism produced extensive ash-flow tuffs that covered large portions of the Basin and Range Province while the Colorado Plateau remained largely unaffected. Volcanic flows and volcaniclastic sediments and areally restricted lahars and air-fall tuffs were also produced. Some of these rock types are associated with vent areas that locally include shallow-level intrusives that might have been situated beneath volcanoes.

Unlike many other areas of the world where this type of silicic volcanism is occurring today, such as the Andes of South America, the Basin and Range Province of Arizona and the Southwest underwent major crustal extension and normal faulting during volcanism. As a result, mid-Tertiary volcanic fields in Arizona were slightly to severely broken by faults and dismembered during or shortly after volcanism. Basalt eruption also occurred during and immediately after silicic volcanism, which produced compositionally diverse suites of volcanic rocks. In addition to structural and geochemical diversity and complexity, variable and locally intense hydrothermal alteration characterizes Arizona's middle Cenozoic volcanic rocks.

Late Cenozoic volcanism in Arizona is dominated by areally extensive basalt flows that are most widely exposed in the Transition Zone and along the southwestern margin of the Colorado Plateau, but includes cinder cones and local siliceous volcanic deposits (Figure 5). Siliceous volcanic rocks of this age are almost entirely restricted to the San Francisco volcanic field in the vicinity of Flagstaff. The most recent basaltic volcanism (less than 1-2 m.y. old) has been largely restricted to the San Francisco, Springerville, and Uinkaret volcanic fields of the Colorado Plateau and the Sentinel, San Bernardino, and San Carlos volcanic fields of the Basin and Range Province. Structural disruption of these rocks is minor to non-existent, and evidence of hydrothermal alteration is sparse.

INDUSTRIAL USES OF VOLCANIC ROCKS

Of the six volcanic episodes, only the mid-Tertiary and late Cenozoic events produced rocks that are substantially exploited today. Volcanic rocks of Precambrian and Jurassic age have been so metamorphosed that they have lost most of the unique properties possessed by volcanic rocks and are best considered metamorphic rocks. Schist derived from metamorphosed rhyolite near Mayer is mined for dimension stone and used in the construction industry as building facade. The qualities that made this material attractive are the result of metamorphism rather than original volcanic processes. Jurassic and Laramide volcanic rocks also have commonly undergone considerable hydrothermal alteration and structural deformation. As a result volcanic rocks from these time periods are generally too unlike their volcanic protoliths to have been quarried for industrial uses. Conversely, because of their widespread distribution and generally fresh to slightly altered condition, middle Tertiary and late Cenozoic volcanic rocks are used by industry where properties unique to volcanic rocks are required.

A variety of middle Tertiary volcanic rocks are used commercially, with those of silicic composition being the most important. Perlite, a rhyolitic glass that contains a concentric "onion-skin" structure caused by cooling and hydration, is present in many parts of the Basin and Range Province. The term "perlite" has been used traditionally to describe any naturally occurring volcanic glass that expands when heated to yield a frothy, lightweight cellular substance similar in some aspects to popcorn. Perlite with excellent expansion (popping) capabilities commonly has the following properties: (1) shiny luster; (2) onion-skin texture; (3) few visible crystals; (4) presence of marekanites; (5) specific gravity of approximately 2.4 g/cc; and (6) 3 to 4 percent water by weight (Wilson and Roseveare, 1945). Marekanites, obsidian nodules known locally as "Apache tears," are small areas of the rhyolitic glass that lack the onion-skin texture (Figure 6).

In 1984 U.S. production of both processed and expanded perlite increased to reverse a 6-year decline. Nationwide, 653,000 tons of perlite was mined in 1984 with New Mexico accounting for 87% of the total; of the six states mining perlite, Arizona ranked third after New Mexico and California (Burgin, 1985; Meisinger, 1985). We estimate that Arizona accounted for 6% of the Nation's total perlite production. Nationwide, processed (not expanded) perlite sold and used amounted to 498,000 tons valued at slightly more than $16.6 million ($33.41/ton) while sales of expanded perlite totaled 404,000 tons with a value of $69.5 million ($172/ton) (Meisinger, 1985). The perlites of Arizona have been historically and are currently used for lightweight and high-strength aggregate, agricultural fertilizer carrier, fire-retardant insulation, acoustical and perlite-gypsum plaster, filtering in the beverage, chemical, pharmaceutical and sugar industries, soil conditioner, chicken litter, molding for foundry sands, and filler for paints and plastics.

Extensive deposits of perlite are exposed at many places within a northwest-trending belt approximately 15 km long by 4 km wide located adjacent to Picketpost Mountain southwest of Superior in Pinal County. These de-

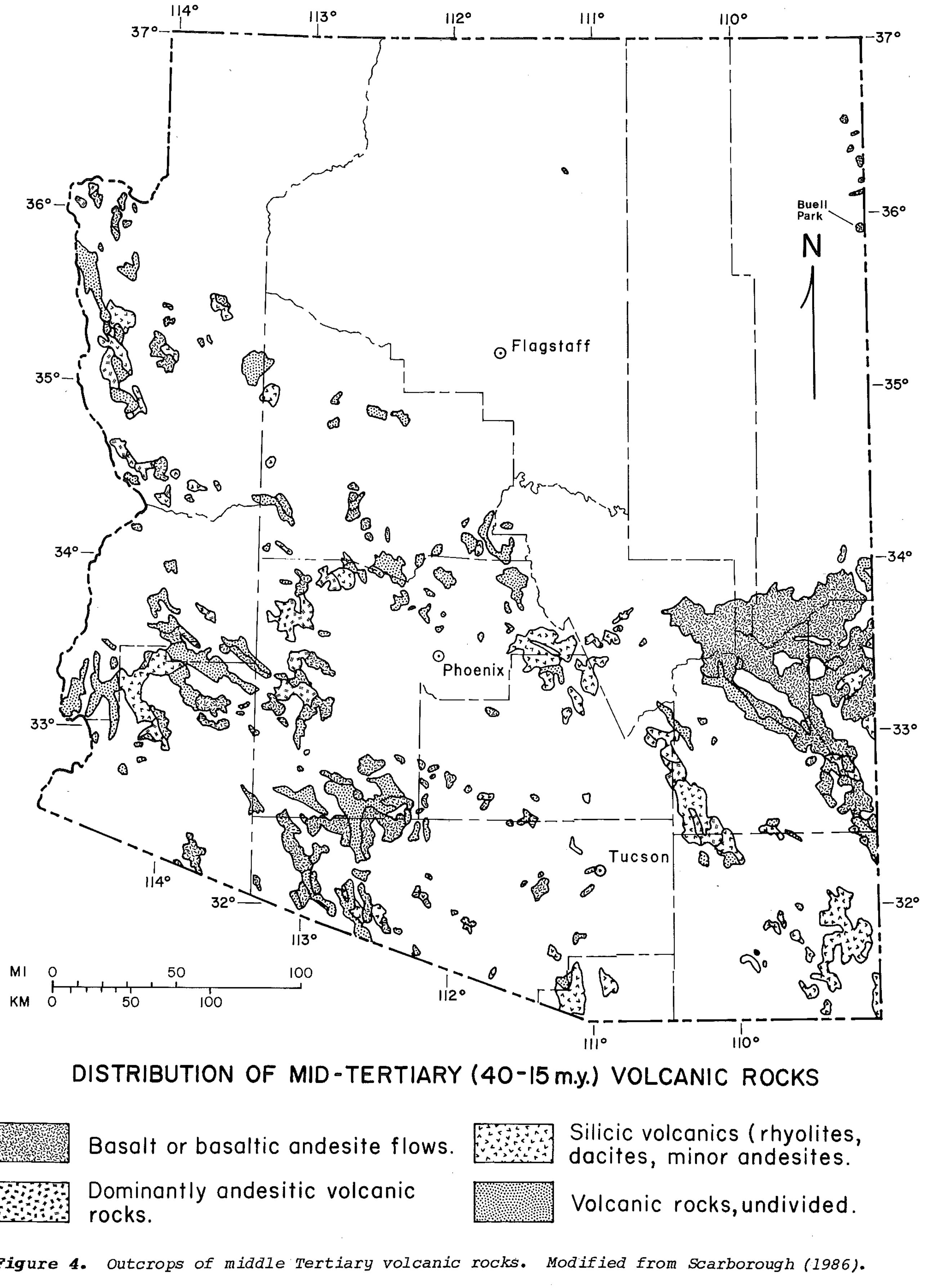


Figure 4. *Outcrops of middle Tertiary volcanic rocks. Modified from Scarborough (1986).*

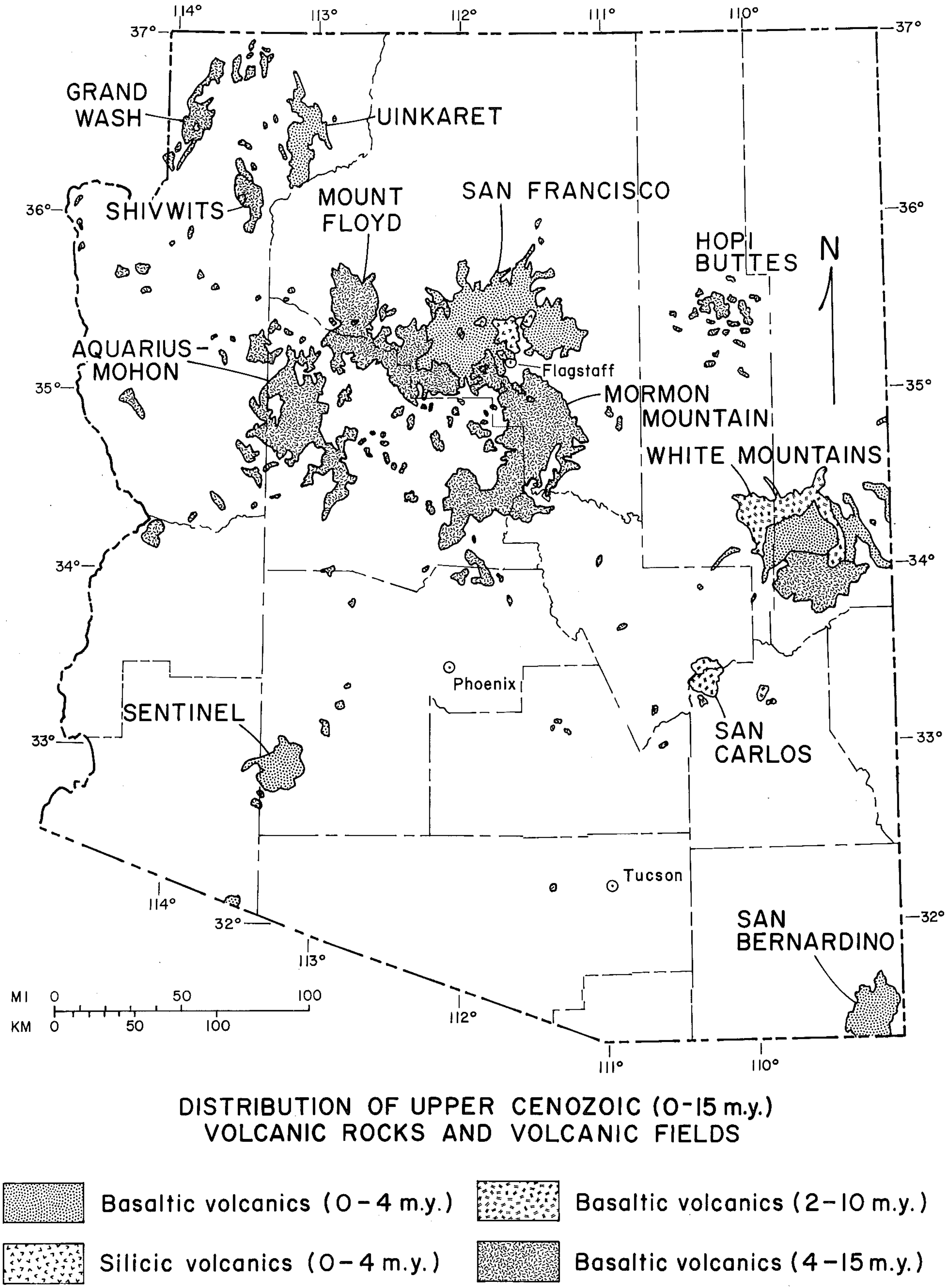


Figure 5. *Outcrops of late Cenozoic volcanic rocks. Modified from Scarborough (1985).*

Figure 6. Marekanites (black spots) or "Apache Tears" in a gray matrix of perlite from the Sil-Flo perlite pit southwest of Superior. Photo by John W. Welty.

posits are of importance because of present commercial development and potential reserves (Peirce, 1969). The geology of the Picketpost Mountain area is described by Lamb (1962) and Peterson (1966).

Middle Tertiary rhyolite lava flows cover the low-lying hills from the northern to southeastern side of Picketpost Mountain. The rhyolite is underlain by Precambrian Pinal Schist and Apache Group metasedimentary rocks, middle Tertiary tuff with local basalt flows, and a volcanic breccia composed of angular fragments of both Precambrian and middle Tertiary lithologies in a pyroclastic matrix. Within the flow-banded rhyolites is a 2-15 m thick layer of perlite that locally exceeds 200 m in total thickness. Overlying the perlite is a similar thickness of non-perlitic glassy rhyolite, tuff, and quartz latite flows. This package of volcanic rocks is largely flat-lying. The perlite appears to thin westward and northward. The commercially exploited perlite is light gray to milky white with strongly developed spheroidal perlitic structure and a vitreous luster. Spheroidal marekanites are scattered through the perlite and collecting them is a local tourist attraction.

Anderson and others (1956) describe the perlite as containing 90% glass with plagioclase, k-feldspar, magnetite and quartz cut by veinlets of cristobalite and pyrolusite. Chemically the perlite ore is high in silica (>70 weight percent), low in iron and alkaline elements, and contains less than 10 weight-percent total alkali elements (Anderson and others, 1956). The perlite contains 3.8-weight-percent water, whereas the marekanites have a very low water content (Keller and Pickett, 1954).

Although other occurrences of potentially expandable volcanic glass in middle Tertiary volcanic rocks of Arizona (see Elevatorski, 1978; Jaster, 1956) offer opportunities for further development, Peirce (1969) suggests that the Superior area is best suited for future growth in the Arizona perlite industry because of its developed infrastructure and access to major transportation corridors. Reserves, however, appear to be limited.

Other uses of middle Tertiary volcanic rocks include the following: (1) pumice mined by the Gila Valley Block Company northeast of Safford for the fabrication of lightweight concrete block; (2) similar deposits near Kirkland in central Arizona that were crushed and sized for the production of cat litter; (3) an opaque opal known as Fire Agate in rhyolitic tuff near Klondyke, Graham County; and (4) basalt southwest of Casa Grande that is used in the manufacture of rock-wool insulation products.

Upper Cenozoic volcanism resulted in the development of numerous cinder cones, particularly on the Colorado Plateau. The San Francisco volcanic field contains at least 200 cinder cones, many with one or more associated lava flows and, one important center of silicic volcanism (Figure 7). Flows and cones have been divided on the basis of stratigraphic and physiographic relationships, degree of weathering and erosion, K-Ar ages, and chemical and petrographic data into five groups ranging in age from Holocene (A.D. 1064) to Pliocene (6 m.y. ago) (Damon and others, 1974; Moore and others, 1976; Smiley, 1958).

The flows and cones are mostly nepheline-normative alkali olivine basalts that, with decreasing olivine content, grade into alkali-rich high alumina basalts. With relative enrichment of potassium and silica, alkali olivine basalts also grade into basaltic andesites. Silicic volcanic rocks consist largely of rhyodacite domes, flows and minor pyroclastic deposits. Basaltic and silicic eruptions were closely associated in space and time. Chemical data from both mafic and silicic rocks suggest that all volcanic rocks were erupted from the same magma source that has experienced a complex evolutionary history. Strontium isotope ratios are generally low (<0.7050), implying that the lavas were generated in the mantle and were not significantly contaminated by crustal material (Moore and others, 1976).

The major center of commercial production of cinders has been from the cinder cones of the San Francisco volcanic field. Superlite Builders Supply obtains cinders from a pit near Winona; Flagstaff Cinder Sales from a quarry in East Flagstaff; Olson Brothers from a quarry in Williams; the Coconino County Highway Department from several pits; the U.S. Forest Service from many quarries; and the Arizona Department of Transportation from

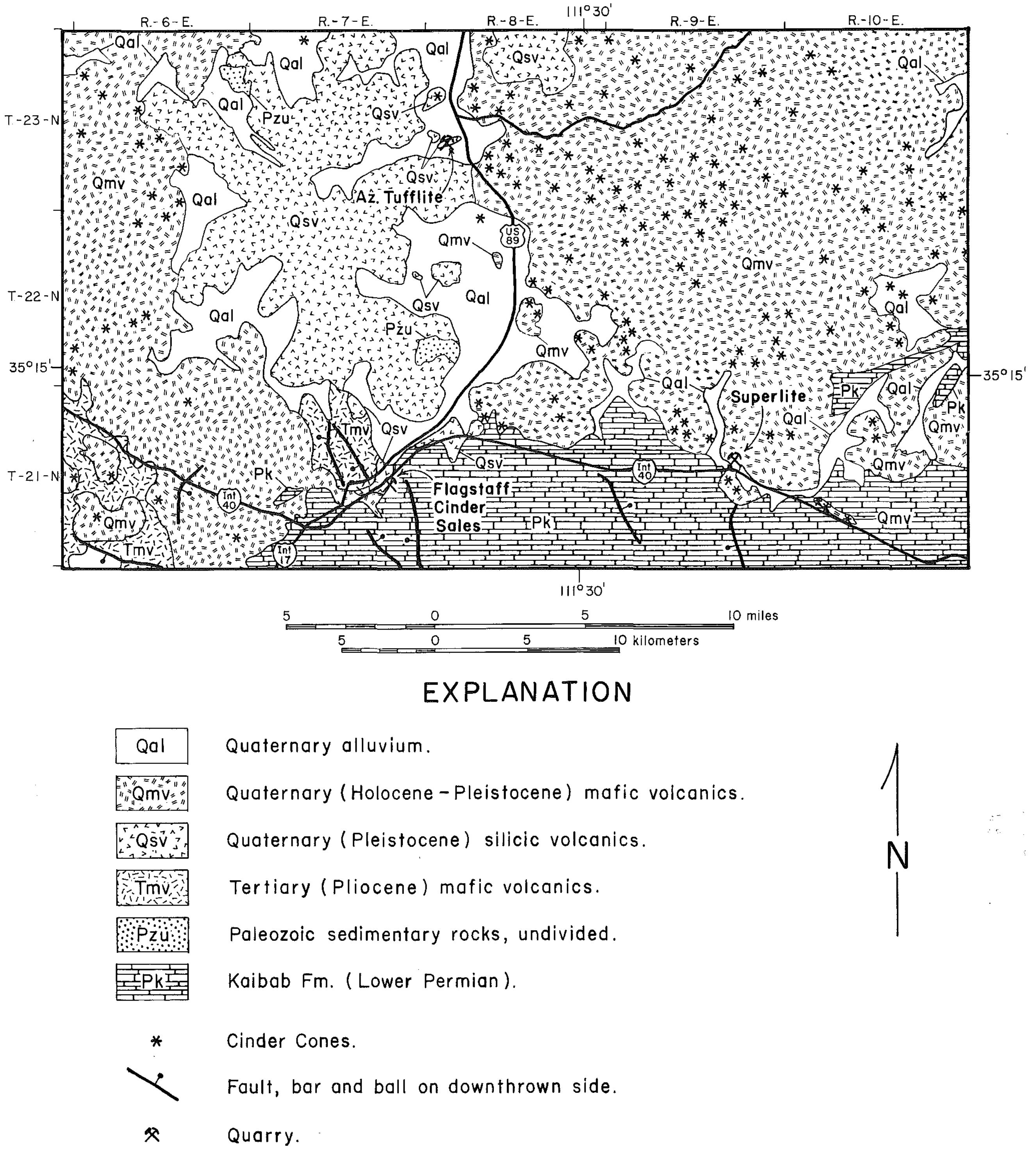


Figure 7. *Geologic map of the San Francisco volcanic field near Flagstaff showing the location of cinder cones and major cinder-producing facilities. Modified from Ulrich and others (1984).*

several pits. These companies and agencies account for the bulk of commercial and noncommercial production of cinders from the San Francisco volcanic field (Figure 7). Perkins Cinders, the Apache County and Navajo County Highway Departments, and the U.S. Forest Service produce cinders for industrial use from the Springerville volcanic field (Figure 5). Past production has come from several small quarries in the San Bernardino volcanic field in southeastern Arizona (Figure 5). We estimate that in 1983 cinder production in Arizona amounted to approximately 600,000 tons. In all of these areas, the cinders display a wide variety of colors from black to magenta. The distribution of and differences among the color types are not well understood, although the color variation is thought to reflect differences in the oxidation state of iron in the magmas from which cinder cones are produced. Peirce (this volume) cites an example where cinder color was of practical importance. Arizona cinders are mined for use as rip-rap, cinder block, aggregate for road base and asphaltic concretes, drilling-mud conditioners, drainage fields for septic systems, winter traction on icy roads, and landscaping.

In the San Francisco volcanic field, the Sugarloaf Mountain rhyolite dome erupted approximately 210,000 years ago (Damon and others, 1974). This eruption produced a layer of rhyolitic tuff that yielded over 200,000 tons of pumice used as pozzolan in the construction of Glen Canyon Dam. Currently the material (different locality) is sold as lightweight aggregate and for landscaping, and Arizona Tufflite, Inc. (Figure 7) is marketing it for use as a pozzolan. Pozzolans are siliceous materials that, when finely ground (to -325 mesh), will form a "natural" cement in the presence of water and lime. Other pozzolans are found near Williams in upper Cenozoic rocks and near Bouse and Safford in mid-Tertiary rocks (Williams, 1966).

Basalt on Peridot Mesa in the San Carlos volcanic field (Figure 5) also contains peridot (gem-quality olivine) that is intermittently sold to rock collectors and stone cutters for mineral specimens and jewelry (Moore and Vujch, 1977). Peridot Mesa, approximately 14 km^2 in area, is capped by a Pleistocene basalt flow that is 3 to more than 30 m thick and is underlain by flat-lying tuff, siltstones, and gravels of Plio-Pleistocene age (Bromfield and Shride, 1956; Lausen, 1927). The peridot occurs as aggregated inclusions in a basalt flow that erupted from a dike source at the southwest corner of Peridot Mesa. Bromfield and Shride (1956) report that an exposure of basalt in Peridot Canyon contains a layer ranging from 2-4 m thick that contains an unusually high concentration of peridot. Peridot occurs in aggregates or masses that comprise 25-40 percent of the rock volume and average from 7-20 cm in maximum diameter. Peridot also occurs in Buell Park on the Navajo Indian Reservation north of Ft. Defiance (Figure 4; Allen and Balk, 1954). In 1984 Arizona led the Nation in gem-stone production with total production valued at $2.7 million; turquoise and peridot, respectively, were the most important contributors (Burgin, 1985). Total peridot production has been declining for several years (Pressler, 1985).

Many volcanic eruptions are accompanied by explosive outpourings of volcanic ash. When ash is deposited in a lake or other body of water, it is subject to alteration to potentially useful products. Two of these products, bentonite clay and the zeolite mineral chabazite, are mined in Arizona and exported for use elsewhere (Seé Eyde and Eyde, this volume; Bowie, this volume). The Bowie chabazite deposit of southeastern Arizona, also of late Cenozoic age, is mined for use as an activated molecular-sieve material (Eyde, 1978).

CONCLUSION

Arizona has experienced a complex volcanic history that has intermittently spanned 1.8 b.y. of geologic time. Volcanic rocks of Precambrian to Laramide age have not been significantly used in commerce as their physicochemical characteristics are not yet known to meet the specifications required for special use. Widespread and voluminous volcanic rocks and related products of middle and late Cenozoic age are used by industry in Arizona and outside the State. The variety of commercial products includes perlite, pumice, basalt, basaltic cinders, pozzolan, semi-precious gem stones, clays, and zeolites. The total value of these products in 1984 is estimated to have been in excess of $3 million. Although the use of Arizona's volcanic rocks is currently limited, volcanic-rock sequences in Arizona are still incompletely known and the potential for recognition and exploitation of important new deposits of useful volcanic-related commodities is high.

ACKNOWLEDGMENTS

We thank H. Wesley Peirce of the Arizona Bureau of Geology and Mineral Technology (ABGMT) for his guidance and encouragement to venture into the world of industrial minerals and rocks, and for the opportunity to take part in the Forum. Steve Reynolds, ABGMT, provided helpful advice about the volcanic history of Arizona, and John Challinor provided information on the Arizona Tufflite, Inc. operations.

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Locating, Sampling, and Evaluating Potential Aggregate Deposits

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ABSTRACT

One of the primary functions of the Geotechnical Services-Materials Section of the Arizona Department of Transportation (ADOT) is locating, sampling, and evaluating potential aggregate deposits throughout the State. This information is essential in designing, estimating, and bidding highway construction projects.

The nature of materials used for aggregate varies greatly within Arizona. The northeastern or plateau section is famous for its scenic sedimentary formations that are, however, too soft to make suitable aggregate. Volcanic materials are widely used in place of more conventional geologic units. In contrast, the southwestern, or Basin-and-Range section, contains a relative abundance of good aggregate, especially a diversity of gravels.

The paper will review the office, field, and laboratory methods used by the ADOT Materials Section in satisfying its needs for aggregate information in Arizona.

INTRODUCTION

A primary function of ADOT, Materials Section, Geotechnical Services, is locating, sampling and evaluating potential mineral aggregate deposits so that the information is available for use in designing, estimating, and bidding future highway construction projects in Arizona. The purpose of this paper is to review some of the methods used in accomplishing this function.

GEOLOGIC SETTING OF AGGREGATES

Geologically, the State of Arizona is composed primarily of two major structural provinces: (1) the Colorado Plateau Province in the north and northeast portion, and (2) the Basin and Range Province in the south and west portion. In general, the type of aggregate found and utilized within the State varies with the province.

Colorado Plateau Province

The Colorado Plateau (CP) Province, in general, consists of gently dipping sedimentary formations that have been intruded and covered by igneous rocks in the volcanic fields surrounding the towns of Flagstaff and Springerville. Except for exposures in the Grand Canyon and along the Mogollon Rim escarpment, most of the exposed sedimentary formations are Permian or younger in age. Unfortunately, most of these younger formations consist of soft shales, siltstones and sandstones, and are not conducive to the development of either durable gravels or crushed rock. As a consequence, most of the aggregates from the CP are quarried from selected rock types such as basalts, felsites, limestones, sandstones, and cinders.

Hard durable basalt is considered an acceptable aggregate. The only exceptions are when it contains basaltic natural glass, nodules of tridymite or cristobalite silica, or clays that are reactive with the alkalies in Portland cement. Also, a blend sand is usually required because the crushed and shot fines often are too plastic. Basalt has a high affinity for bitumen therefore is excellent in preventing the stripping of asphaltic concrete pavements.

Light-colored, fine-grained igneous rocks are collectively known as felsites. The felsite group includes andesite, rhyolite, dacite, and trachyte. Although usually hard and durable, they commonly contain silica glass, opal, and chalcedony, all of which are reactive to Portland cement. Also, they are commonly hydrophilic (high water absorption ability) and have low bitumen absorption properties. Another problem is flow structure, which causes felsites to fracture in the crusher into elongated flat plates that are hard to work and require more cement and sand than an ideal, blocky-shaped aggregate. Many of the darker felsites are mistaken for basalt, but unlike basalt, this aggregate has more deleterious features to watch for.

Some types of limestone, mainly from the Permian Kaibab Formation (caps the western half of the plateau), contain enough calcium and magnesium carbonates (70%) to be an acceptable aggregate. However, because of poor frictional qualities as a consequence of polishing, it is not considered desirable to use limestone aggregate in the surface of a roadway. Again, a blend sand is sometimes needed.

Most sandstones in Arizona, because of inferior abrasion qualities, are not used as an aggregate with asphaltic concrete. Some sources, however, have been used as a base material, and as a subgrade seal.

In some parts of the plateau province cinders are the only known aggregate available over large distances. Cinders are used by the building block industry in Arizona for aggregate. However, cinders are not considered as desirable as other aggregates for road building because of problems with porosity and open grading. These properties not only cause excess asphalt to be used, but the percent of voids filled varies with the temperature when mixed, giving mix-design problems. In cool weather the mix has stability but lacks cohesion, which would cause cracking of the pavement. In hot weather the mix has cohesion but lacks stability, which causes rutting in the pavement. Also, many cinders have a high abrasion value and break down into a plastic material. Cinders, though generally unsuitable for aggregate, are still used in winter by ADOT to spread on icy roads.

Basin and Range Province

This region constitutes the Arizona desert as most people think of it. Although the annual precipitation indicates an arid desert, much of the rain comes in a few violent storms of short duration causing flash floods. Moreover, the larger rivers that cross the province have tributaries that reach into the higher country along the southern margin of the CP Province, thus contributing to rapid runoff. While this province is topographically lower than the CP, parts of it are structurally higher, which causes the older crystalline rocks to be exposed. The land, in general, is characterized by over one hundred individual mountain ranges that alternate with basins filled with materials eroded from the developing mountains. Although these fault-block mountains vary in rock types and structure, a pattern repeated over and over is a sloping surface (piedmont) of varying width between range front and basin center. The ranges, several million years old, have been wasting throughout their existence. The sedimentary deposits on the piedmonts constitute a complex of interbedded lensing materials that include some of the best gravel aggregate in Arizona (Figure 1). Coating and cementation of older alluvial deposits (often called "fanglomerates") with clay, caliche ($CaCO_3$), or silica, renders the gravels undesirable for most construction purposes. Too, a wide variety of parent materials, both "good" and "bad", have contributed to the gravels from place to place. Slates, schists, and gneisses are inferior to quartzites, limestones, and marbles. Many of the volcanics are of the felsite group and have the same negative aspects as they do on the plateau.

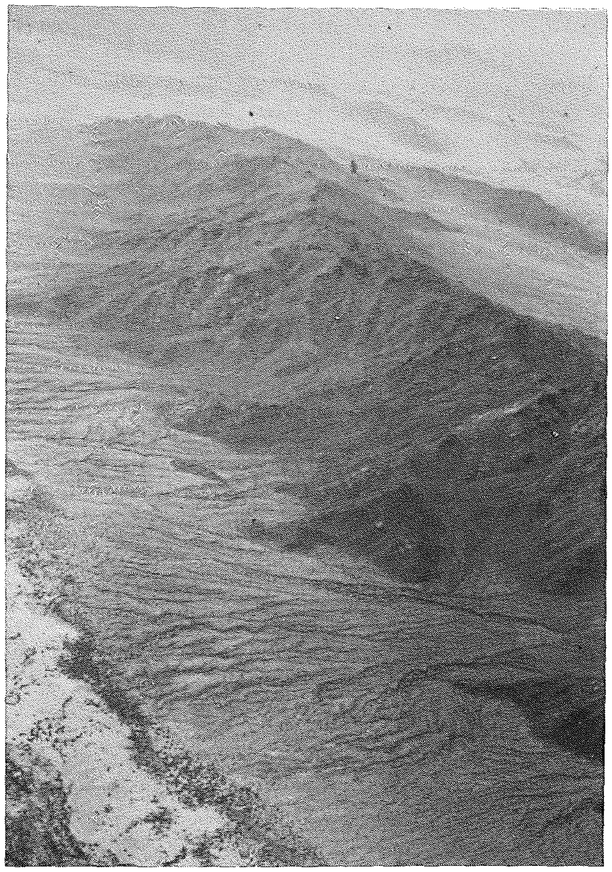

Figure 1. *Aerial view of the Sierra Estrella mountains near Phoenix showing a narrow piedmont slope at the mountain base. Piedmonts are often a source of gravel aggregate. Looking southerly.*

LOCATION

The main purpose of any prospecting program is, of course, locating a deposit. This is done in two steps (a) office review, and (b) initial field review.

Office Review

A comprehensive office review is the first step in locating an aggregate source. The initial sources of information are the Materials Inventory Folios, maintained by the Materials Section since 1958. These folios have four principal parts (1) pit location and air-photo coverage map, (2) geologic information including a photogeologic map, (3) land status map or land ownership map, (4) pit data sheets with test results of material found at each pit, and past-use record. The base map used for the folios is a county-map series published by the Photogrammetry and Mapping Services units of ADOT. These include drainage patterns, section, range and township lines, and major utilities.

A preliminary list of promising pits is compiled from the folios, and the information is updated from our active-pit files and topographic, geologic, and land status maps. In addition, a check is made with Photogrammetry and Mapping Services for new aerial photos. After a review of all information, a final list of potential sites is compiled.

Initial Field Review

The initial field review is made to evaluate the information developed in the office review. Existing pit sites are visited and an attempt is made to determine if these sites can be enlarged either in depth or in area. Possible new sites, noted on aerial photos or geologic maps, are also visited. Preliminary sampling and land-survey-monument location may also be done at this time. Unsuitable pit sites are eliminated and sampling is begun on those remaining. The criteria used for determining the most appropriate sites are discussed under "Preliminary Evaluation".

SAMPLING

Natural deposits of aggregate seldom exist in conveniently graded conditions and without overburden. The methods of sampling, therefore, are very important. Without representative samples, accurate evaluation of the quality and quantity of aggregate in a deposit is impossible.

Sampling Quarry Sources

In sampling quarry-rock sources, a rotary drill rig is used to determine depth and areal limits. Useful information can be obtained from observation of the drill cores or cuttings, the rate of penetration, and the sound. Diamond core, tricone, drag, down hole hammer, and jackhammer bits are used. Both air and water are available for circulation.

At least one test hole is shot. If the material appears suitable, samples are obtained for testing and evaluation. The test hole is logged for record and changes noted. If there is more than one type of material each should be represented by a 60 pound sample. The words "Quarry Crush" should appear on all identifying tags. Also, two samples of each of the usable strata should be taken and marked "For Abrasion", with a minimum of three samples for the entire pit.

An additional sample should be taken of the fines generated from the blasting operation and combined with an equal amount of fines extracted from seams, fractures, or bedding planes exposed in the test hole. This sample should be marked "For Information Purposes", and will be tested to determine the need for wasting of natural and shot fines.

Sampling Sand and Gravel

For sand and gravel a backhoe is used to determine depths and areal limits. Although a drill rig is often used for this purpose, a backhoe is considered preferable because the material can be observed in place. In addition, it is nearly impossible to obtain representative samples of sand and gravel deposits with a drill rig. Unless uniformity of material allows fewer holes tests are spaced 100 feet apart. A summary of the size and number of samples required is listed in Table I. Immediately after the test hole has been excavated and is ascertained to be safe for entry, the field man proceeds with a prescribed sampling procedure.

Sampling Oversize Aggregate

The percentage of materials retained on the 3-inch and 6-inch sieves in aggregate pits is important because, from a cost point of view, it indicates the amount of crushing required; it determines the ultimate coefficient assigned to aggregate in the pavement-design procedure, and it influences the job-mix formula in asphaltic concrete-mix designs. For these reasons, it is important to make an effort to determine as closely as possible the amount of oversize rock. The steps involved include selection of holes to be sampled, sampling, and weighing.

Table 1. *Aggregate tests and sampling requirements.*

Type of Test	Number of Samples	Size of Each Sample
1. Sieve Analysis and P.I.	1 for each stratum of each test hole	25-30 lbs.
2. Density	Minimum of 3 for each pit.	75-100 lbs.
3. pH and Resistivity	Minimum of 3 for each pit.	25-30 lbs.
4. Abrasion	Minimum of 3 for each pit.	60-75 lbs.
5. Job Mix	Minimum of 12 for each job mix.	25-50 lbs.
6. Oversize	Minimum of 1 for each job mix.	75-100 lbs.

PRELIMINARY EVALUATION

During or after the sampling process, and before the holes are backfilled, a materials engineer or geologist reviews the proposed pit and decides if the quality of the material is high enough to use as aggregate alone, or as an asphaltic concrete aggregate. Other factors considered are quantity, quality, uniformity, geologic origin, and numerous development questions. Development questions include flooding, position relative to water table, response to erosion, zoning or governmental regulations, slope stability, vegetative removal, road requirements, haulage requirements, and environmental parameters. The latter, in turn, include visibility, noise, surface drainage, land-use effect, flora and fauna, blasting effects, etc. If, after considering these factors a pit appears suitable, then the material samples are sent to the laboratory.

LABORATORY TESTING AND FINAL EVALUATION

The principal aggregate tests include gradation (sieving), hydrometer testing for sizing material below 200 mesh, ph and resistivity test for corrosive or reactive salts, abrasion, compressive strength of concrete specimens, and petrographic analysis. The latter is useful in evaluating various quality aspects of rocks proposed for aggregate use (Figure 2).

Additional tests are run when the routine aggregate testing indicates that the quality may be high enough for use in asphaltic concrete. Many of these tests are run on the anticipated mixture of aggregate and asphalt. These include stability under traffic, immersion compression (reaction to water), voids analysis (porosity), cohesion (tested under tension), absorption, specific gravity, etc.

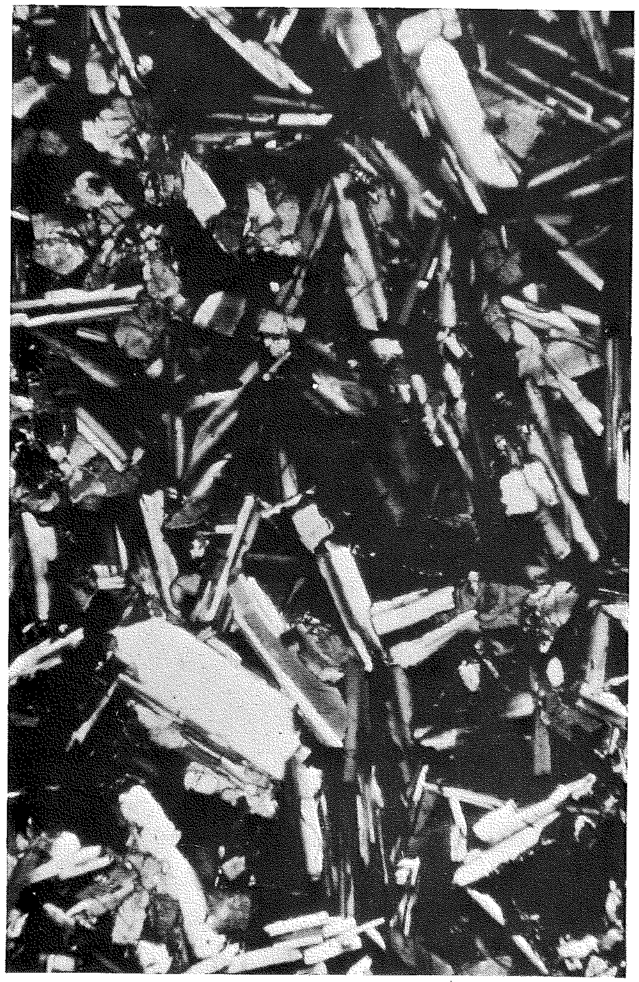

Figure 2. *A microscopic view of a fresh, durable basaltic volcanic rock suitable for making crushed aggregate. Crystals are randomly oriented plagioclase feldspar in a fine-textured matrix.*

CONCLUSION

In order for the design engineer to have a dependable basis for making final plans and specifications, the process of locating, sampling, and evaluating potential aggregate sources must be carried out early in a highway project investigation. Solving the problems will invoke the skills and methods of various people. Such work involves the close cooperation of a team of geologists, material engineers, and field and laboratory technicians. Sources of quality aggregates are being depleted in many areas. Zoning, right-of-way, environmental and other considerations are reducing or eliminating many existing and potential sources. Consequently, it is becoming increasingly difficult to develop new sites. This often necessitates the use of aggregates having marginal quality. The ability to establish criteria for accepting or rejecting such materials, which usually have no known service record, cannot be overemphasized.

Solar Salt in Arizona

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ABSTRACT

Southwest Salt Company is solution mining the Luke Salt Body of probable late Miocene age. The discovery hole, from which the first core was recovered, was drilled in 1968. The deposit was encountered at a depth of 880 feet, and the bit was still in salt at the bottom-hole depth of 4,500 feet.

The solar ponds, developed on land formerly dedicated to agriculture, have an annual capacity of about 90,000 tons. Because land values are very high, mining rates and procedures are governed by the need for near-saturated brine to minimize land requirements.

Because of the frequency of dust storms, the salt operation uses a unique wet-harvesting method. Most inventory is kept in the ponds under brine and harvested only a few days before shipment. Studies of the nature of crystal growth and the distribution of windblown and brine impurities led to the development of procedures for processing salt of high chemical purity and low insolubles content. Chemical purity exceeds that of most salt produced in fuel-fired evaporators.

Salt is shipped from Phoenix as far east as west Texas and as far west as central California. Occasional shipments have been made to Hawaii and Alaska.

DISCOVERY-GEOLOGY-PRODUCTION

My interest in developing a salt industry in Arizona was first stimulated by Dr. H. Wesley Peirce of the Arizona Geological Survey. After reviewing all acquired information, I made arrangements to drill an exploration hole in the bull's-eye of a gravity low in sec. 2, T. 2 N., R. 1 W., Maricopa County (Figure 1). In November 1968, the exploration-drilling venture entered solid rock salt at a depth of 880 feet beneath a cotton field. Available funds supported additional drilling to 2,800 feet, still in salt. At this time El Paso Natural Gas Company, which was interested in establishing a subsurface natural-gas storage facility in western Arizona, was contacted and told of this geologic development. The company immediately supported both the deepening and eventual logging of the hole. The hole was finally terminated at a depth of 4,503 feet (3,400 feet below sea level), still in salt! More than 3,600 feet of halite, with minor interbeds of insolubles (shales, etc.) were cut. It is this section that is being exploited for salt by solution mining and in which subsurface storage cavities were engineered by an adjoining operation.

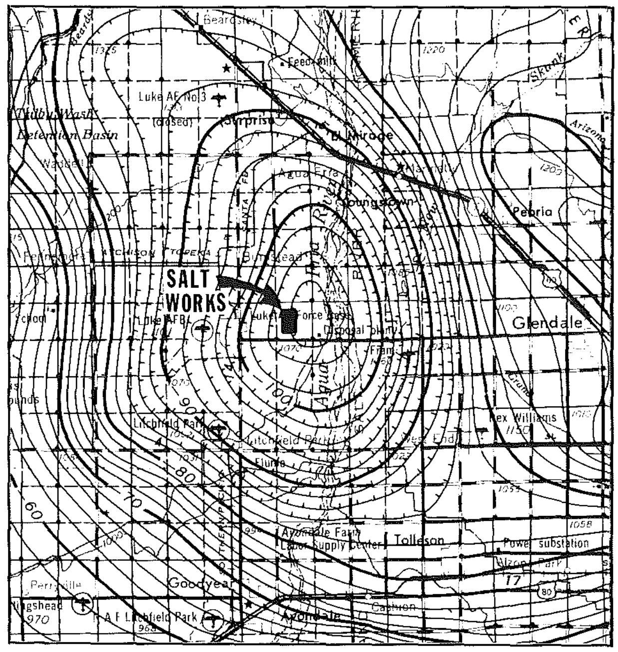

Figure 1. *Map of portion of Bouguer gravity map showing location of the salt works with respect to the gravity-negative center of the Luke Basin. From Peterson, D. L., 1968, U.S. Geological Survey map GP-615.*

Eaton and others (1972) named the salt mass the Luke Salt Body and generated a multiple-hypothesis approach to its origin. Petroleum geologists, always on the alert for new frontiers, were intrigued by a diapirism-doming model and the related implications. Peirce (1974, 1976) refers to the mass as the Luke Salt and suggests that it, though slightly deformed, was deposited in a paleobasin during Miocene time.

A production company, Southwest Salt, was formed. It demonstrated the feasibility of a solar-salt project that could produce an exceptional grade of salt. A contract was made with California Liquid Gas Company in which Cal-Gas developed storage caverns on a portion of Southwest Salt's leased property and Southwest used the brine. Southwest Salt has its own brine wells independent of the adjacent liquid petroleum gas (LPG-butane, propane) storage caverns project.

A search for a precedent operation in a strict desert environment found none that produced salt low in insolubles. Desert storms load the solar ponds with debris and in operations such as this, sand and dust are usually not removed. Although winds carry dirt almost daily in the Phoenix area, dust storms occur primarily during July and August and occasionally during April and November. Such storms often deposit enough material to cover the salt completely. Studies showed that the ponds annually collected between 1/8 and 1/4 inch of windblown dirt. Because the total salt crop averaged 12 inches per year, 1 to 2 percent of annual production consisted of dirt.

Equipment was developed to harvest the salt without draining the ponds. This allows harvesting at intervals regulated to minimize entrapment of dirt in the salt crystals. It also eliminates the difficulty that a dust storm might cause to a drained pond, in which dust could dry on the salt and make separation very difficult. The final-harvest flowsheet features one man operating a wheeled dredge pulled by a crawler tractor, which in turn is driven by an electric-motor hydraulic system (Figure 2). Power is supplied by a trailing mine cable encased in a high-density polyethylene pipe with floats as necessary.

The dredge pipeline is also made of high-density polyethylene. This line carries a brine-salt slurry to a wash plant where dewatering, screening, and screw-type washing equipment separates salt from brine. After being washed, the salt is stockpiled by stacking conveyor (Figure 3). Only the wheeled dredge and crawler is custom-built. The separation and washing plant is an assembly of standard equipment that removes almost all of the windblown dust and dirt.

Insolubles typically range from 0.01 to 0.02 percent (100 to 200 parts-per-million). In one full production test to determine the ultimate performance capabilities, insolubles were reduced to 40 ppm, calcium plus magnesium to 12 ppm, and soluble impurities to less than 100 ppm.

Although the plant has not been built to FDA specifications, the salt is considerably purer than most salt produced in vacuum pan evaporators for use in foods. The low calcium content is useful in curing sausage and in similar applications in which phosphates are used instead of nitrates. Calcium ties up phosphates and changes the taste of cured foods.

Contracts are routinely made for production of salt with the calcium-plus-magnesium content at 35 ppm typically and 50 ppm maximum. At this degree and purity, a sales price can be assigned that is high enough to cover shipment costs to destinations such as San Antonio, Texas and Sacramento, California.

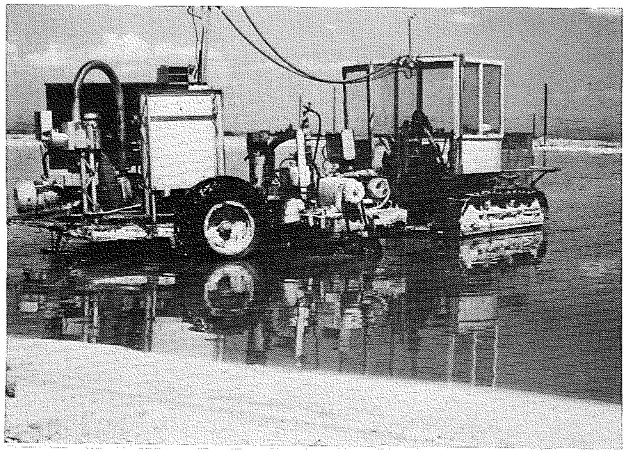

Figure 2. *Photograph of salt-harvesting device in brine covered salt evaporation pond.*

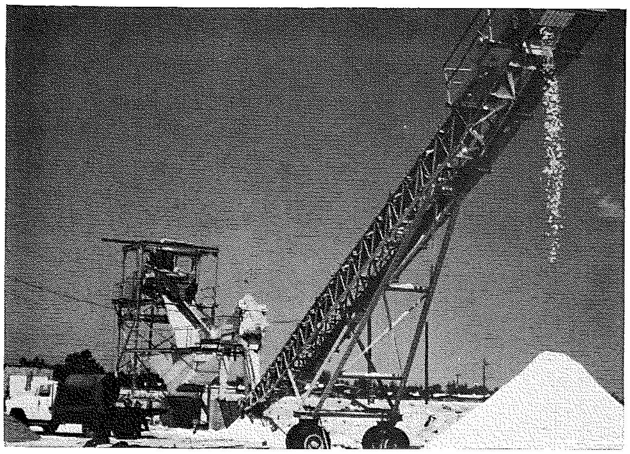

Figure 3. *Photograph of wash plant, stacking conveyor, and stock pile.*

This Arizona operation has introduced new technology to one of the oldest process industries. The substitution of solar energy for the four million BTU/ton used in vacuum-pan evaporators comes at an appropriate time. Salt operators from several foreign countries have visited the operation, seeking new technology. The harvesting method is adaptable to any size of operation for which slurry pumps are made. This method, plus the one-man operation, allows low entry investment and low operating costs that make small-tonnage operations competitive with customary megaton operations.

This new method of producing high-quality salt at costs competitive with larger operations serves to decentralize the salt industry where the climate allows solar ponds and a salt source is available. Solar-salt production is important to developing countries where markets are smaller, transportation is less available, and energy costs are higher than in the industrialized nations.

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Bentonite and Specialty Sand Deposits in the Bidahochi Formation, Apache County, Arizona

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ABSTRACT

Specialty sand and bentonite are produced in the plateau province from the Bidahochi Formation near Sanders, Apache County, Arizona. It appears that deposits of both sand and bentonite formed during the Pliocene in fluvial and lacustrine environments, respectively, along the west side of the Defiance Uplift.

The bentonite is an alteration product of airborne vitric ash that fell or was washed into lakes. In the Cheto district, the individual bentonite horizons, which range from less than a foot to more than 10 feet thick, are restricted to the position of the medial volcanic member. Bentonite production began at the Allentown mine in 1924 and the Chambers mine in 1926. In 1933 strip mining of the extensive deposits in the Cheto district commenced. Production increased each year to a peak of 270,000 tons in 1957. As a result of the introduction of synthetic zeolites into petroleum refining, production declined. About 40,000 tons of bentonite are currently produced from the district each year. Bentonite is shipped out of State for processing into desiccants, thickeners, and acid-activated clay products.

The specialty sand was derived from Permian sandstones and deposited by streams draining the Defiance Uplift. Although stream channels are usually restricted to the upper member of the Bidahochi, stratigraphically above the bentonite horizon, a few actually cut through the bentonite. The well-sorted sand, suitable for use as a proppant in hydraulically fractured oil and gas wells, is localized in elongate lenses along the margins of the channels. These lenses range from 5 to 50 feet in thickness and often extend thousands of feet in both width and length. The sand is about 97 percent silica, has a yield of 40 percent in the minus 20 plus 40 mesh size fraction, and has a roundness of 0.6 to 0.7 on the Krumbein scale. Production of this sand began about 1961. All of the current production, which amounts to about 40,000 tons per year, is sold in the petroleum-producing area near Farmington, New Mexico.

INTRODUCTION

Specialty sand and bentonite are produced in the plateau province from the Bidahochi Formation near Sanders, Apache County, Arizona (Figure 1). Bentonite from the Bidahochi

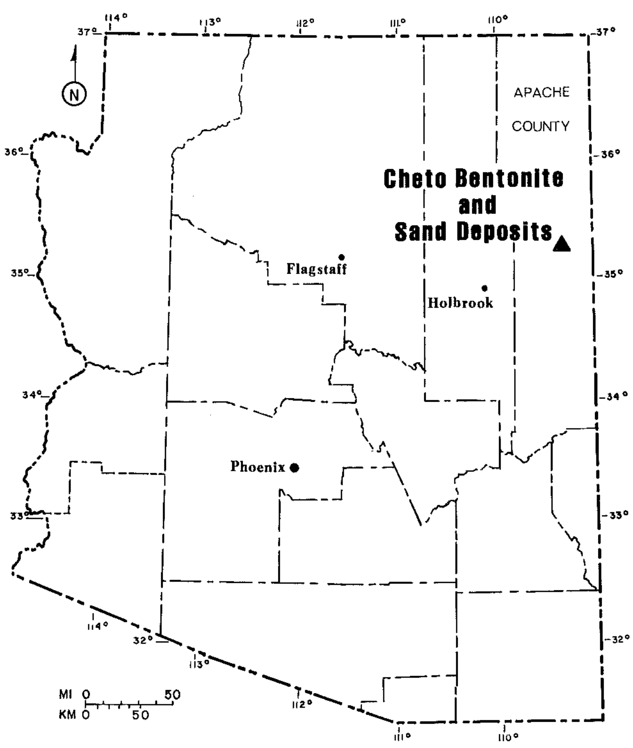

Figure 1. Map of Arizona showing location of Cheto bentonite and sand deposits.

Formation was used in the original cracking catalysts at oil refineries. This application was quickly displaced, however, when synthetic zeolites with their smaller cavities and superior properties became commercially available. Bentonite is currently used in acid-activated and desiccant applications.

The crude bentonites now being mined are processed at plants in New Mexico, California, and Mississippi. The products and their per-pound values include high value-added desiccants ($0.36 - $0.50), acid-activated bentonites ($0.10 - $0.20), and thickeners and gellants (more than $1.00).

The Cheto bentonite deposits in the Bidahochi Formation formed during the Pliocene in a series of interconnected lakes on the west side of the Defiance Uplift. The bentonite is the alteration product of vitric ash deposited in the lakes in at least two horizons. These horizons now range from less than a foot to more than 13 feet in thickness. The bentonite is a remarkably pure dioctahedral calcium montmorillonite member of the smectite group of clay minerals. It is the nearly monomineralic composition, a high crystallinity, and the large surface area that produce the extraordinary sorptive properties.

The most serious problem facing the operators in the district is the increasing overburden thickness, which now averages nearly 100 feet. In certain areas, a thick bed of hydrofrac sand occurs in the overburden and may offer opportunities to produce an additional salable product, thus reducing overall stripping costs.

Proppant sand production from the upper member of the Bidahochi Formation began in 1961 from deposits in the Houck area, Navajo Indian Reservation. Though sand is a mineral resource believed to occur almost everywhere, deposits of sand suitable for use as a proppant in hydraulically fractured oil and gas wells are uncommon. Deposits of these specialty sands were derived from uplifted and reworked Permian sandstones and deposited in a fluvial environment near the southwest part of the Defiance Uplift.

The hydrofrac-sand products are the minus 10 plus 20 and the minus 20 plus 40 mesh fractions. The products are about 97 percent silica, have a roundness of 0.6 to 0.7 on the Krumbein scale, and have a low acid solubility. Oil-well service companies have been using about 80,000 to 100,000 tons per year to complete oil and gas wells in the Farmington, New Mexico area. The Arizona Silica Sand Company has been supplying about 40 to 50 percent of this market.

Hydrofrac sand is a high value-added specialty sand product that sells for more than $25 per ton f.o.b. the plant. Production from the Arizona Silica Sand deposit at Houck is restricted because homes have been constructed on the westward extension of the deposit. Nearly identical deposits of sand overlie parts of the nearby Cheto bentonite deposit just off the Navajo Reservation.

Both Filtrol Corporation and United Catalysts Incorporated operate surface bentonite mines in the Cheto bentonite district. The Filtrol operation is now stripping about 90 feet of overburden to mine about 25,000 tons of bentonite per year. United Catalysts strips 85 feet of overburden to mine about 12,000 tons of bentonite per year. At both mines, the bentonite bed averages 5 feet in thickness.

Bentonite from the Filtrol mine is shipped to Jackson, Mississippi for processing into bleaching clays used as desiccants and to clarify edible oils. In the past, virtually all of the bentonite from the United Catalyst mine was sold to Culligan USA for processing into desiccants at their plant in San Bernardino, California. In October 1983, United Catalysts opened its processing plant at Belen, New Mexico, about 50 miles south of Albuquerque. At that time, Culligan was notified that United Catalysts would supply only processed bentonite. As a result, Culligan is now purchasing crude bentonite from a somewhat lower quality deposit in Sonora, Mexico.

Location and Land Status

The more recent drilling data are from Arizona State Mineral Leases controlled by Engelhard Corporation in sec. 16 and 36, T. 21 N., R. 29 E., Apache County, Arizona. When the State of Arizona issued the mineral leases to Engelhard Corporation, the surface and mineral estate of these sections belonged to the State. In 1985, however, surface rights were transferred to the Bureau of Land Management (BLM) to hold in trust for the Navajo Tribe as part of the Navajo and Hopi Indian Relocation Amendment Act of 1980. The BLM also acquired the Wallace and Roberts ranches, which owned surface rights to sections surrounding State sections 16 and 36. The mineral estate of these lands was not acquired. The Santa Fe Railroad Company, which owns the mineral estate under 140,000 of the 250,000 acres being acquired by the BLM for the Navajo Indians, has filed a $200-million lawsuit requesting compensation for their mineral properties. Because of the transfer of surface rights to the Navajo Tribe, Santa Fe believes that access to any fuel- or nonfuel-mineral deposits discovered on the split-estate lands may be denied by the Tribe. The State of Arizona retained the mineral estate on sections 16 and 36. It is the State's position that the leases the State issued on these lands remain in full force and effect. An agreement, however, must be negotiated with the Navajo Tribe to ensure unrestricted access to the Indian lands.

It is still unknown when or if the BLM will transfer title of the surface estate of these trust lands to the Navajo Tribe. Reportedly, the Navajos must take possession of these lands by July 1986. Complicating this transition is a lawsuit filed by the Navajo Tribe to block implementation of the Joint Use Relocation Act. This could result in the BLM retaining the lands now held in trust for the Navajos. If this were to happen, the land would probably be managed under multiple-use guidelines. In any case, this is an example of an important and valuable natural resource potentially made worthless by a poorly conceived and implemented Federal program.

GEOLOGY

Kiersch and Keller (1955), while investigating the mineral resource potential of the Navajo Indian Reservation, described the geology of the nearby Cheto clay deposits in detail. Their work is summarized and updated by exploration drilling completed between 1978 and 1983.

The bentonite deposits originated from the alteration of a vitric ash approximating quartz latite in composition. Deposition was approximately contemporaneous with that of the medial or volcanic member of the Bidahochi Formation. Bentonite deposits occur in channels and basins above the lower member and may extend a few feet into the upper member. The clay outline does not conform to the ash contact in all places. These depositional traps contain most, if not all, of the known bentonite deposits. Although related rhyolitic to basaltic ash beds are common elsewhere in the Bidahochi, the particular environment of this area and the latitic composition of the vitric ash seem to have controlled the alteration to bentonite.

The bentonite is invariably overlain, and in some cases underlain, by reddish or tan silt. Normally both the upper and lower contacts with silt are sharp. Where the silt is admixed with clay, however, usually near the margins of basins and channels, the sand content of the clay may increase to 4 to 6 percent, a prohibitive concentration for commercial use.

The bleaching-clay deposits predate the first coarse sand lenses or lenticular beds of the upper member of the Bidahochi Formation. Deposits of bentonite rarely occur directly beneath an outcrop of these sands or immediately adjacent to sand pinchouts. Instead, high-purity bentonite deposits occur at some distance from pinchouts and at stratigraphically lower horizons within siltier strata.

Although high-grade bentonite deposits average from 3 to 5 feet in thickness, a 13-foot bed was sampled in drill holes southeast of the Cheto pits. This variation in thickness may be due to an undulating depositional floor, irregular erosion of the deposit, or lateral position in the deposit with respect to its margins.

The Bidahochi Formation was deposited primarily on an irregularly eroded surface of older rocks. The pre-Bidahochi surface, similar to that which exists today, consisted of stream channels, lake basins, and other surface irregularities. Volcanic ash falls occurred during medial Bidahochi time and covered most of the landscape. The latitic ash filled stream channels and depressions. It appears that a considerable part of the ash was vitric and that this material was further concentrated in permanent streams, small lakes, and ponds by current flow. The source of the ash is speculative, but several possible volcanic centers were active near the boundary of the Bidahochi basin. The lakes contained fresh water that had a greater concentration of calcium and magnesium than sodium, the bentonite being a calcium montmorillonite.

Between 1978 and 1983, 37 rotary-core holes were drilled to explore the bentonite deposit in sec. 36, T. 21 N., R. 29 E. in the Tolopai Spring 7.5- minute quadrangle. Thirty-six of these intersected bentonite. This widely spaced drilling program defined the size of the bentonite deposit and the overburden depth. In 1981 the exploration drilling discovered a second bentonite bed about 30 feet below the main bed. Analytical results showed that both the upper and lower beds were similar mineralogically and could be used to make desiccants that meet military specifications. This lower horizon has yet to be exploited. Earlier drilling in nearby section 16 intersected a deposit of hydrofrac sand overlying the bentonite. Cuttings from the drill holes in section 36 were therefore routinely logged for sand attributes.

Based on the sampling and analytical work, a hydrofrac-sand deposit overlying the bentonite was identified in the northeast quarter of section 36. The potential yield is higher than that from other deposits, including those mined by Arizona Silica Sand Company on the Navajo Indian Reservation. Between 1983 and 1985 sand from section 16, off the reservation, supplemented the feed to the company's plant in Houck. Tests by Arizona Testing Laboratories in Phoenix and Core Laboratories, Inc. in Corpus Christi, Texas, determined that the roundness and sphericity, size distribution, and composition equaled or exceeded that of the hydraulic-fracturing sand produced by Texas Mining Company and Pennsylvania Glass Sand Company from the Brady deposit at Voca, Texas.

Hydraulic-fracturing sands are used as proppants after a well is hydraulically fractured to stimulate oil and gas production. Arizona Silica Sand Company's production of 40,000 tons per year supplies about 40 percent of the hydraulic-fracturing sands consumed by oil and gas wells in the Farmington, New Mexico area. The sand product sells for $25 to $28 per ton f.o.b. the plant at Houck, Arizona.

PRODUCTION AND MARKETS

Calcium Bentonite

Bentonite production began in 1924 when 30 tons of nonswelling calcium montmorillonite was shipped from the Allentown mine. Filtrol Corporation contracted for the production from the Chambers underground mine in 1926. During the 1930's, both the Filtrol Corporation exploration department and C. A. McCarrell began exploration programs to locate other bentonite deposits in the district. As a result of these efforts, the Cheto mine, a surface operation, began production in 1933.

The underground operation at the Chambers mine closed in 1938, leaving the Cheto surface mine as the only producer in the district. The Cheto mine yielded 11,616 tons of bentonite during its first year of operation. Production increased to 144,000 tons in 1949, 250,000 tons in 1954, and a peak of 270,000 tons in 1957. Production then steadily declined for many years. In 1961 production was 50,000 tons, and according to the Arizona Department of Mineral Resources, production in 1975 reached a low of about 20,000 tons from the Filtrol mine. The other operation in the district, the Gurley bentonite mines, produced about 5,000 tons during 1975. District production since 1975 has doubled to about 40,000 tons per year. All of the clay produced is used in high value-added markets including clay desiccants, specialty clay gellants, and acid-activated bentonites. These products sell for $0.10 - 2.00 per pound. The largest producer in the district is the Harshaw-Filtrol Partnership, which is managed by Kaiser Aluminum and Chemical Corporation. Currently 25,000 to 30,000 tons of calcium montmorillonite are mined from the Harshaw-Filtrol properties and shipped to Jackson, Mississippi by rail for processing into desiccants and acid-activated clay. The Jackson, Mississippi acid-activation plant has a reported capacity of 80,000 tons per year of product. Up to 20,000 tons of Cheto clay are blended with Mississippi and Louisiana calcium bentonites to produce several grades of acid-activated clay products, which sell for $300 to $400 per ton and are sold under the Filtrol trade names. Harshaw-Filtrol is also a major producer of clay desiccants. Filtrol annually used as many as 10,000 tons of Cheto bentonite in this application. In July 1984, Filtrol announced that the clay-products plant in Jackson, Mississippi would double its desiccant-production capacity.

The other major producer at the Cheto bentonite deposit is United Desiccant Corporation, a subsidiary of Sud-Chemie AG, a major West German clay company. United Desiccant controls a bentonite resource at Cheto estimated at about 1.5 million tons. The company purchased the reserve from C. E. Gurley for a reported $3.5 million in 1980. The clay from this operation is shipped by truck to Belen, New Mexico for processing into desiccants and to Louisville, Kentucky for processing into specialty clay gellants sold under the Tixogel trade name. Originally, United Desiccants sold crude clay to Culligan Corporation for processing into desiccants. But on completion of the Belen plant, only processed clays were sold.

Acid-activated clays are calcium montmorillonites that have been treated with acid to improve their physical properties. The chemical and physical properties of the final product are dependent on the source clays, the feed-clay particle size, and the specific activation process used. In the United States and Canada, the Harshaw-Filtrol partnership dominates the industry with an estimated 100,000 tons per year of capacity, or nearly 20 percent of the world total. American Colloid Corporation has entered the U.S. market with a plant in Aberdeen, Mississippi and began production in November 1985. The capacity of this operation is reported to be 12,000 tons per year.

Producing clay desiccants adds value to the clay through packaging rather than processing. The processing is relatively simple. The crude clay is dried, crushed to minus 3 mesh, and heated to remove the water. Once the clay has been activated, it must be packaged. The packaging process puts a measured portion of clay into permeable paper or other containers, ranging in size from 1 gram to more than a kilogram, which readily allows water to be absorbed by the desiccant.

In summary, 40,000 tons per year of clay mined at the Cheto bentonite deposit generate or contribute to products that have total revenues estimated at $42 million per year. No other deposit presently in production in the United States can match the unique physical and chemical properties of the Cheto bentonite.

Proppant Sands

Hydraulic-fracturing sand is a specialty sand used by oil-field service companies as a propping agent in the stimulation of both old and newly completed oil or gas wells. When a well is treated, fractures in the producing strata are opened by pumping a sand-bearing fluid down the well bore and into the reservoir under extremely high pressures. When the pressure is released, the sand grains prop the fractures open so that the oil and gas can flow more freely into the well.

Because of the high compressive pressures and corrosive environment in oil wells, hydraulic-fracturing sands must meet rigid physical and chemical specifications. The sand must have a high SiO_2 content, preferably above 97 percent. The individual sand grains should be well rounded to allow free movement of the sands into the fractures. Contaminants, such as calcite or feldspar, are undesirable.

Grain size is especially important. The oil field service companies, such as Halliburton and Dowell prefer the minus 20 plus 40 mesh size, although sometimes a coarser sand, minus 10 plus 20 mesh, is used. When evaluating sands in Texas, Oglebay Norton determined that the deposits must have at least 40 percent plus 40 mesh and 25 to 30 percent minus 20 plus 40 mesh to be economic. Lesser amounts of coarse sand and finer sand are tolerated because they can be sold for filter, blast, and foundry sand. About 50 percent of the total crude sand mined is screened and washed; the remainder returns to the pits as tailings.

The sand or sandstone deposits must be amenable to open-pit mining. In Texas, Oglebay Norton (Texas Mining Company) and Pennsylvania Glass Sand Company mine a friable sandstone that has to be drilled and blasted. This sandstone is so friable that little wear is produced on the crusher jaws. The sand grains are cemented by a thin clay coating that washes off easily in the wash plant. At Cheto, the sand is unconsolidated and is mined with a front-end loader. All of the sands must be washed, screened, and dried.

There are very few sand or sandstone deposits in the United States capable of producing proppant sand. Ottawa Silica produces fracturing sands from the St. Peter Sandstone in Illinois, plus an array of other silica products. Oglebay Norton and Pennsylvania Glass Sand Company produce from the lower Hickory Sandstone of Upper Cambrian age in central Texas. This is the only formation known to contain fracturing-sand deposits in Texas. Arizona Silica Sand produces from a deposit at Houck. Sand deposits near Fountain, Colorado produce a poor-quality fracturing sand.

The use of sand as a proppant in the hydraulic fracturing of hydrocarbon producing formations began in 1949. The markets for hydrofrac sand grew rapidly through the 1970's at 10 to 20 percent annually, along with the rapidly increasing oil and natural gas prices. In 1980-81, the growth in consumption slowed with the decline in energy prices. Consumption remained stable at between 1.5 and 1.8 million tons annually through 1983. Falling oil prices appear to have stimulated the markets for proppant sands in 1984 and 1985 as a result of the increased emphasis on shallow, low-cost production wells. Based on preliminary data from the U. S. Bureau of Mines, consumption of proppant sands totaled 2 to 2.1 million tons in 1985. The price of this material ranges from $22 to $28 per ton f.o.b. the Arizona plant.

The proppant-sand deposits at Cheto are the westernmost in the United States. Arizona Silica Sand supplies about 40 percent of the hydraulic-fracturing sand used in the oil fields near Farmington, New Mexico. Arizona Silica Sand's closest competitors are Texas Mining Company, a subsidiary of Oglebay Norton, and Pennsylvania Glass Sand Company, now a subsidiary of U.S. Borax. Both produce hydraulic-fracturing sands from a deposit near Brady, Texas. The Arizona Silica Sand Company product enjoys a significant price advantage over the Texas producers, based on freight rates. Furthermore, because Arizona Silica Sand Company mines an unconsolidated sand in an arid area, it does not have to blast or pump water from the pit, as do both of the Texas producers. As a result, its mining costs are lower.

FUTURE

Known geologic reserves of bentonite in the Cheto district are under lease. At the present rate of removal, these reserves seem adequate for the forseeable future. Less is known about the overall distribution of reserves of specialty sand. Much of the remaining resource potential, however, appears to be spacially similar to the clay distribution. Although the geologic factors appear favorable, pending political factors cloud the future of these relatively scarce nonmetallic materials.

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Mexico's Industrial Minerals

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Although Mexico is known for its important base-and precious-metal deposits, and lately oil, some industrial minerals play an important role in the Mexican economy. Sulfur, the most important industrial mineral produced, accounts for approximately 7.5 percent of the total value of mineral production. This commodity is followed by fluorspar, which accounts for 6.4 percent. Predominantly, the fluorspar deposits are very high grade (75 percent CaF) and are contained in lower Cretaceous limestone in the states of Coahuila and San Luis Potosi. Base-metal deposits in the area of Parral (notably San Francisco del Oro), however, have become important fluorite producers in their own right. (San Francisco del Oro has 12 percent fluorite gangue.) Salt from the Guerrero Negro solar-evaporation ponds in Baja California account for 6 percent of the total shares; phosphate from Baja California also accounts for 6 percent. Barite from manto deposits in Lower Cretaceous limestone in Coahuila and exhalative deposits in the Paleozoic section of Sonora account for 1.0 percent. In addition, Mexico is an important producer of gypsum, graphite, and celestite. Although graphite and celestite are not large-scale operations and thus do not contribute much to the Mexican economy, the Mexican graphite and celestite deposits are among the most important in the world; Mexico is one of the world's few sources of celestite. The celestite is in the form of large, high-grade mantos in Cretaceous limestones in northern Mexico.

Approach to Locating High-Quality Aggregates in the Basin – Range Province

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Recent experience over extensive areas of the Basin and Range Province has demonstrated the importance of the basin's (valley's) geology and geomorphology in locating large quantities of good-quality aggregate.

First, a geologic map depicting basic geomorphic-geologic units in a valley is made in the office from aerial photography. Next, derivative maps are made from geologic maps and field-derived information such as parent rock type, source area and depositional environment, relationship to adjacent deposits, and Quaternary geologic history.

Studying the derivative maps leads to selection of test sites for potential deposits of high-quality aggregates. Subsequent field studies provide more detailed information about geologic processes and samples for laboratory testing. Combining all information allows the characterization of aggregate potential of very large areas. Favorable areas can be further tested. This phased approach has proven to be cost effective.

The methodology used in mapping and characterizing basinfill deposits is applicable over much of the western United States. Map units were developed by focusing on the predominate geomorphic process, grain size, cementation, and relative age. The resulting functional map units are of use to engineers and planners.

This study led to many conclusions, including the fact that the best quality basinfill aggregates are found in selected alluvial fan deposits and Pleistocene lakeshore deposits. The best quality aggregates are derived from Paleozoic carbonate and quartzitic parent materials that can also provide high-quality crushed-rock aggregates.

Geologic Evaluation of the Southern Portion of the Searles Lake, California Brine-Saturated Evaporite Deposits: An Update

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The evaporite deposit at Searles Lake consists of alternating brine-saturated saline beds and saline-bearing mud beds. Three major subsurface brine-saturated saline horizons have been identified by private companies and the U.S. Geological Survey. They have been termed, from bottom to top, the Mixed Layer, Lower Salt, and Upper Salt.

The important water-soluble components (Na, K, Mg, CO_3, HCO_3, SO_4, Cl, and B_4O_7) are either in brines or have combined to form the following minerals: halite, hanksite, trona, nahcolite, burkeite, borax, thenardite, northupite, sulfohalite, glaserite, etc. Kerr-McGee Chemical Corp., the current operator at the lake, selectively pumps interstitial brines from each of the major horizons to feed its three chemical plants. As the pumping continues, brines are continuously replenished within the deposit by dissolution of the minerals through natural recharge or artificial fluid injection (solution mining). The brines are processed to produce a variety of chemical products, which include sodium carbonate and sulfate, potassium chloride and sulfate, sodium borate, and boric acid.

The Anaconda Minerals Co. has been evaluating potential domestic trona acquisition since 1981. We have evaluated various properties in the Green River, Wyoming trona district, and Owens Lake and Searles Lake in southern California. In 1983, we purchased with our joint-venture partner, Leslie Salt Co., the southern portion of Searles Lake from Occidental Petroleum Corp.

Since mid-1983, Anaconda has been conducting a small exploration-drilling program at the property. The initial core holes were drilled along and adjacent to the existing access road. In 1984 we used an all-terrain drill rig to gain access to drill sites on the playa where no roads exist. The use of this equipment proved to be highly successful.

The drill program consists of coring to an average depth of 450 feet and collecting brine samples from potentially commercial horizons. The brine samples are collected by setting a packer and swabbing the hole. The core is logged and split lengthwise; one-half is submitted to our Tucson Geoanalytical Laboratory for semi-quantitative mineralogy by X-ray diffraction and the following suite of chemical analyses: Na, K, Mg, CO_3, HCO_3, SO_4, Cl, B_4O_7, Li, H_2O insolubles, and acid insolubles. Additional test work for selected core samples will include effective porosity and horizontal permeability determinations. The brine samples are subjected to the same suite of chemical analyses (minus insolubles) as the core samples. In addition, specific gravity is also determined.

Both cross sections and isopach maps are being constructed. The hydrological characteristics of the potentially commercial horizons are also being investigated.

Raw Materials and the Manufacture of Vitrified Clay Pipe in Arizona

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The Building Products Company is Phoenix based and owned by Mission Clay products of California. Building Products is the only manufacturer of vitrified clay pipe in Arizona. The marketing area includes Arizona, Nevada, Utah, New Mexico, and California.

Building Products, promoted by Arizona Public Service, was formed in 1970. Raw-materials prospecting was undertaken for 2 years, after which a $5-million plant was built. Initially, a satisfactory vitrified product could not be made with the raw materials then in hand. Subsequent prospecting and testing led to an acceptable raw-materials mix. Testing to upgrade the final product is a continuing process.

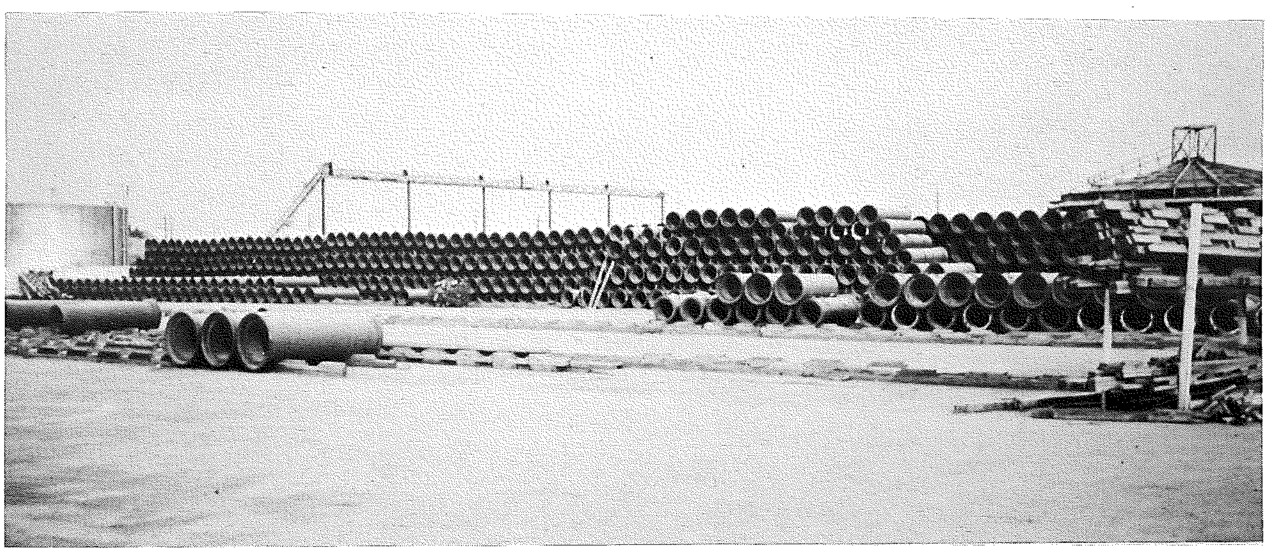
The basic raw-materials supply must be adequate, secure, and capable of sustaining close tolerances in the final product. These needs are met by mining four geologic materials at three different localities: (1) refractory aluminous shales (two horizons-one pit) Colorado Plateau Province (Mogollon Rim); (2) less refractory aluminous materials from late Cenozoic lacustrine materials near Dewey in the Transition Zone (TZ); and (3) Precambrian "slate" from near New River along the southern edge of the TZ.

Other additives include grog (ground-up, broken pipe) and barium carbonate that ties up what gypsum there is. Calcium magnesium carbonates are deleterious components that are minimized by careful selection of the mined products.

The raw materials are blended and mixed, ground to 12 mesh, mixed in a pug mill, depleted of air, extruded into pipe ranging from 6 inches to 42 inches in diameter, transported to a hot-air drying room, fork-lifted to an appropriate kiln, and fired at a 1900-2000° F range.

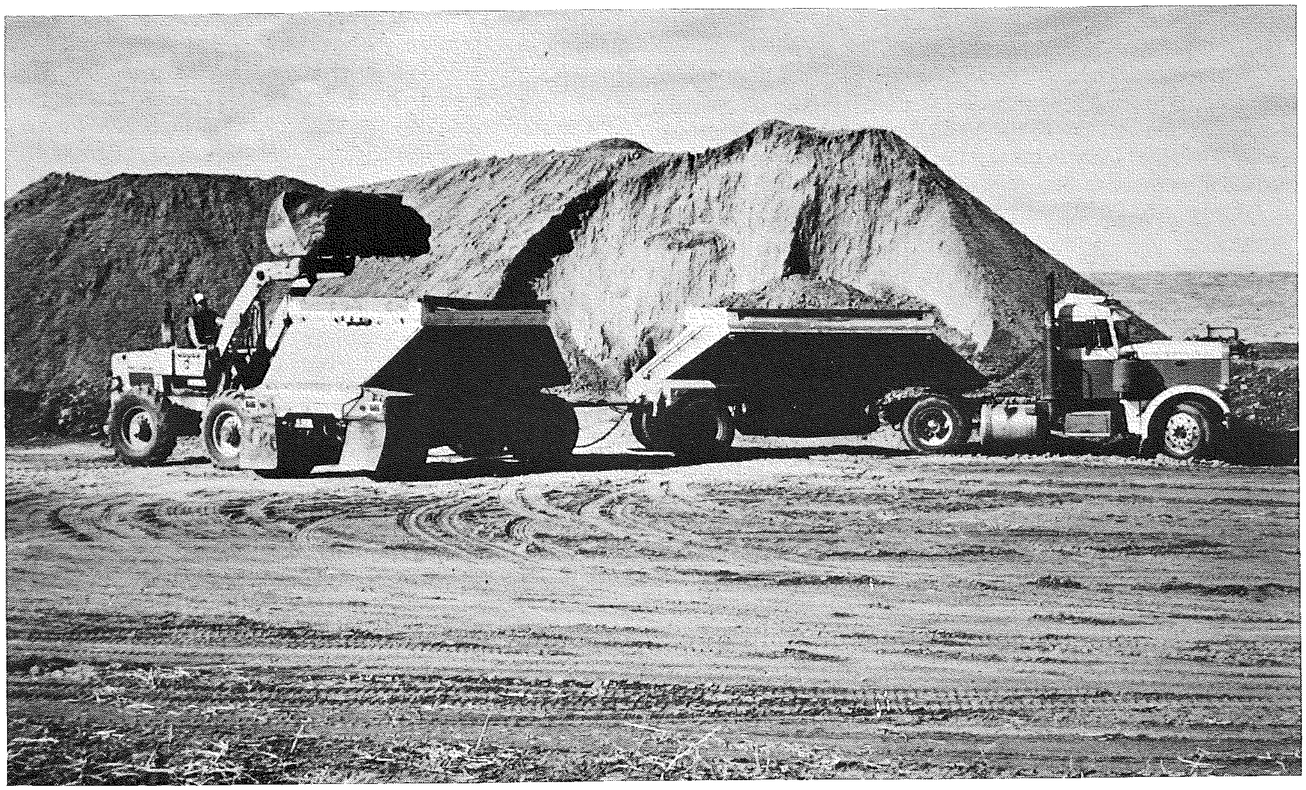
The "Rim" kaolinitic shales, being the most refractory ingredient, stabilize the pipe during the firing process. They are very plastic, and therefore facilitate extrusion. The Dewey clay fuses at a low temperature and forms an impervious glasslike binder. It also is plastic. The "slate" forms platy particles that tend to orient themselves during laminar flow. This provides strength for both the green and dried product. It doesn't absorb water, which helps the drying process. Grog remains stable during firing, and therefore helps to control shrinkage.

The development of appropriate raw materials and proper mixtures has been done empirically.



Vitrified clay pipe in storage at Building Products Company facility near Phoenix.

Source of refractory aluminous shales of Cretaceous age on the southern edge of the Colorado Plateau near Pinedale.



Source of less refractory aluminous materials from late Cenozoic lacustrine materials in the Transition Zone near Dewey.

The Bowie Chabazite Deposit

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The Bowie chabazite deposit has yielded the most mined tonnage of any natural zeolite deposit in the United States. Since 1962 the deposit has yielded about 12,000 tons of crude chabazite, with an estimated market value of $30 million when sold as an activated molecular -sieve product.

Between 1,000 and 1,500 tons of high-purity crude lump chabazite is now produced annually by stripping and selectively mining the lower, massive, half-foot-thick, "high-grade" bed. All of the chabazite is still shipped out of State for grinding prior to extrusion and activation.

Zeolite minerals were discovered at the Bowie deposit in 1875, when Oscar Lowe identified a hydrous silicate related to chabazite or stilbite from a tuff bed that cropped out in the San Simon Valley. It was not until 1959, however, that chabzite, erionite, and clinoptilolite were positively identified as the principal constituents of an altered vitric-tuff horizon that crops out in the area originally described by Lowe.

Shortly after the rediscovery of zeolite minerals in the San Simon Valley, several of the major producers of synthetic zeolites acquired land positions covering the outcrops, including projected extensions, and began exploration drilling. By 1980 all of the known chabazite reserves had been acquired by five companies and two individuals.

The more than 3,000 holes drilled to explore the deposit and the excellent exposures provided by the strip-mined areas indicate that the chabazite-bearing horizon (known as the marker tuff) is confined to a flat-lying lacustrine section known to the operators as the Green Lake Beds. The deposition of the parent airborne vitric ash and subsequent zeolitic alteration was controlled by many factors, including the lake-bottom topography, depth and cation content of the saline-alkaline lake water, and proximity to post-depositional erosion surfaces.

Zeolitic alteration was complete when an extensive system of younger paleochannels deeply eroded the Green Lake Beds. This left only a few erosional remnants of the marker tuff and the lower "high-grade-bed" that constitute the present deposit. Both the channel gravels and the Green Lake Beds are overlain by a section of halite-bearing brown mudstones, known as the Brown Lake Beds. The Bowie chabazite deposit can be used as a model to guide the exploration and development of other zeolite deposits that formed in saline-alkaline lacustrine environments.

Arizona Portland Cement Company's Rillito Operations

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Arizona Portland Cement Company's limestone deposit (called Twin Peaks) is approximately 4 miles southeast of the cement plant. The pant is adjacent to both the Southern Pacific Railroad and Interstate 10, about 17 miles northwest of Tucson.

Placer claims were filed on the Twin Peaks deposits in 1923. From that time until the present, geologic data have been accumulated and evaluated to define more closely the quantity and quality of the limestones.

The cement plant at Rillito was originally constructed as a one-kiln plant in 1949. Capacity was increased in 1952 and 1956, bringing the plant to an annual capacity of 44,000 tons of cement. In 1972 another expansion program was completed, bringing annual cement capacity to 1.1 million tons.

Geologically, the Twin Peaks contain formations ranging from the Precambrian Pinal Schist to the Pennsylvanian Naco Formation. Within this sequence, other exposed formations include the Cambrian Bolsa Quartzite and Abrigo Formation, Devonian Martin Limestone, Mississippian Escabrosa Limestone, and Pennsylvanian Naco Formation.

Generally, the Escabrosa, Naco, and Martin Formation are the primary sources of limestone for manufacturing cement. The Martin Formation is basically a dolomite with bands of limestone, quartzite, and siltstone. These limestones are blended with outside source materials (clay and iron ore) to make a raw mix that will make specification cements.

Several drilling programs were initiated between June 1946 and March 1982. Information derived from these programs provided the means to develop cross sections, geologic blocks, and grade blocks. The configurations of the geologic and grade blocks are the same. Block boundaries delineate the various formations on any particular level.

Cursory inspection of the structure would indicate a broad syncline elevated on the west side. A more detailed examination shows that the structure has been complicated by several periods of faulting and intrusion of igneous rocks.