FIELDNOTES
From The State Of Arizona
Bureau Of Geology And Mineral Technology

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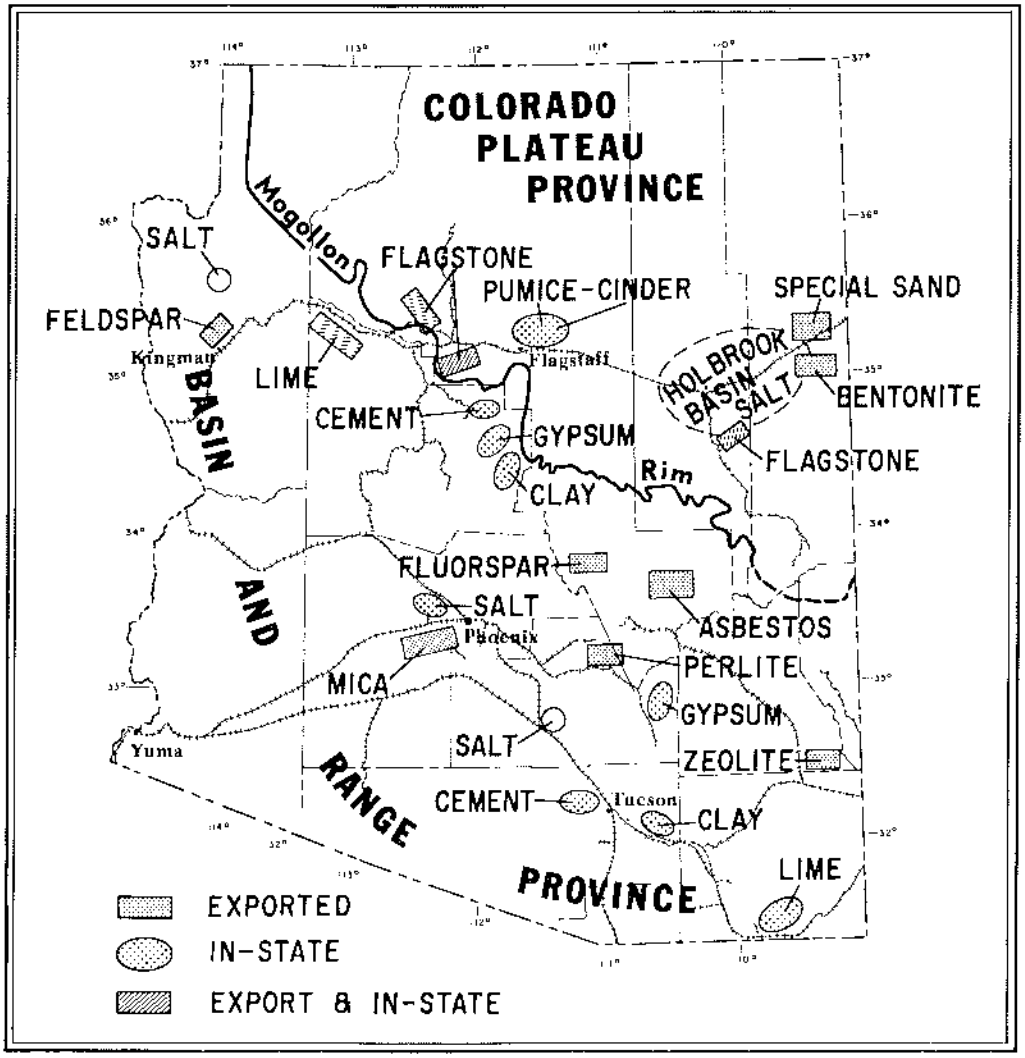
INDUSTRIAL MINERALS AND ROCKS OF ARIZONA

by H. Wesley Peirce

INTRODUCTION

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" fantasies, as do the romanticized metals such as gold and silver. At today's prices, one ounce of gold is equal to about 200 tons of commercial sand and gravel. Which would you rather have? Chances are that gold is perceived as neater – it would better fit a strong box. However, someone has to do the "dirty" work if we are to have the conveniences (houses, roads, and so on) 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 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 the high volume, low value, essential industrial minerals.



Map of Arizona showing railroads, major geologic provinces, and selected industrial mineral commodities presently being produced.

In this issue

OVERVIEW

Five figures have been developed to help summarize highlights of the industrial minerals industry in Arizona. Three of these contain commodity-related names that can be consulted, should the reader be unfamiliar with the kinds of materials that characterize Arizona IM (industrial minerals) production.

As might be expected, Arizona's IM industry is strongly influenced by population and industrial growth and the condition of the economy. We are the sixth largest state in area and have been number one in population growth over the past decade. Figures 1 and 2 reflect the growth pattern in IM output in terms of tonnage. As can be seen in Figure 1, growth, as reflected in value, is misleading because of severe inflation. Between 1950 and 1960, IM tonnage output per resident had increased from about four to 16 tons per year. Except for periods of depression in the business cycle, this higher rate seems to generally prevail. As suggested in Figure 2, the largest growth item, in terms of tonnage, has been sand and gravel. Also, it is interesting to note the consistency in percentage contribution through time that each of the four groups represented tends to make each year, regardless of the amount of total production.

Although the land area of the State is about equally divided between the Plateau to the northeast and the Basin and Range country to the southwest (see map, p. 1), it is the latter province that has received the lion's share of the growth. In fact, over 92% of the populace lives in Basin and Range territory. Considering the large influence of construction on IM output, especially sand and gravel, it is not surprising to learn that 98% of the 1978 IM production came from this growth region. In terms of tonnage and value, commodities exported from Arizona (see map, p. 1), though geologically interesting and individually important, are quantitatively small.

Figure 3 attempts to rank Arizona's IM and products as to value per short ton. That which is most basic and used locally in largest quantities (sand and gravel, brick clay, cinders), has the least value per unit. That which is used in relatively small quantities (zeolite) and is exported has the highest value.

Figure 4 depicts the general production history of certain nonmetallic commodities and groups. According to the record, *clays* have been exploited continuously since before 1900. However, salt, all of which was imported prior to the 1970's, is the newest of the industrial minerals now being produced in Arizona.

Although the 1978 value of overall Arizona mineral production exceeded $1.6 billion, only 10% of this, or about $170 million, is attributed to the nonmetallic industrial minerals. Combined cement and lime approached $85 million, sand and gravel $65 million, stone $10 million, and all others about $10 million. Perhaps it should be recalled that monetary value is not always a measure of usefulness. Isn't it true that the best things in life are free? How about relatively cheap?

In the remaining paragraphs I should like to selectively discuss some aspects of the rocks and minerals that make an Arizona industrial minerals industry possible.

Limestones

Among the most versatile of the rocks of Arizona, and the world, are the limestones, especially the high-calcium varieties most suited to the manufacture of Portland Cement and lime. Arizona is reputed to have the largest lime-making plant west of the Mississippi River and also one of the largest cement plants (Rillito) in the West. Crushed limestone is utilized in many ways, including railroad ballast, filter stone, flux stone, rip-rap, road base, aggregate and sugar refining. The prime souce of Arizona's high quality limestone that enters into cement and lime manufacture is a marine sedimentary rock that was deposited in a shallow, warm sea about 300 million years ago. The rock is a carbonate sand consisting largely of fragments of fossils known as *crinoids*. Most of the lime that winds up in the concrete of our houses was originally extracted from sea water by these animals. This particular rock averages about 400 feet in thickness where present in the State. It is buried beneath the Plateau by younger rocks and is exposed only in the Grand Canyon and along the base of the Mogollon Rim in central Arizona, where it is exploited in the Verde Valley. Geologic mapping reveals that this rock is not present in Maricopa County, the home of Phoenix, because of subsequent removal by erosion. However, it reappears near Tucson where it is an important industrial commodity.

Sand and Gravel

Sand and rock fragments, mixed with cement and water, make concrete, perhaps the most basic of construction materials. It would be ideal to find a deposit that contains just the right proportions of sand and crushable, durable rock for concrete needs. However, it seldom happens. Usually, excess sand has to be moved in order to get enough rock to crush. Sand and gravel deposits occur along modern channelways and on adjacent floodplains and terraces. It is the quality of the gravel that determines the suitability of a deposit. In turn, it is the ultimate source of the gravel that controls the utility of a deposit. It is a mistake to think that high quality gravel deposits occur just anywhere. They don't. In spite of the fact that there are good quality gravels associated with several of the Phoenix area channelways, none could satisfy the concrete aggregate specifications that attend the Palo Verde Nuclear Power Plant presently under construction near Phoenix. As a consequence, gravel is being hauled from as far away as the Colorado River region near Yuma.

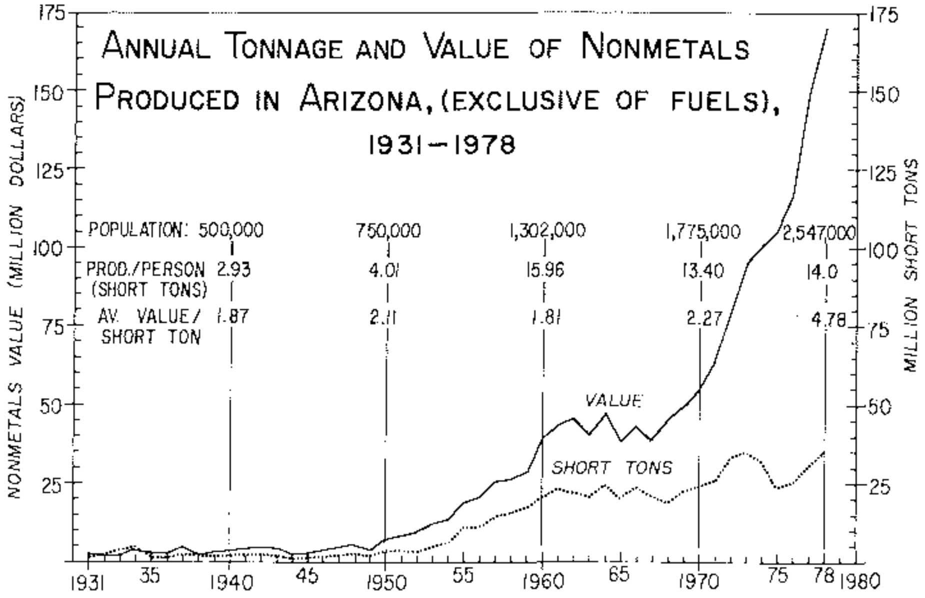


Figure 1, *IM.* Annual tonnage and value of industrial minerals produced in Arizona, 1931-1978 (see population statistics).

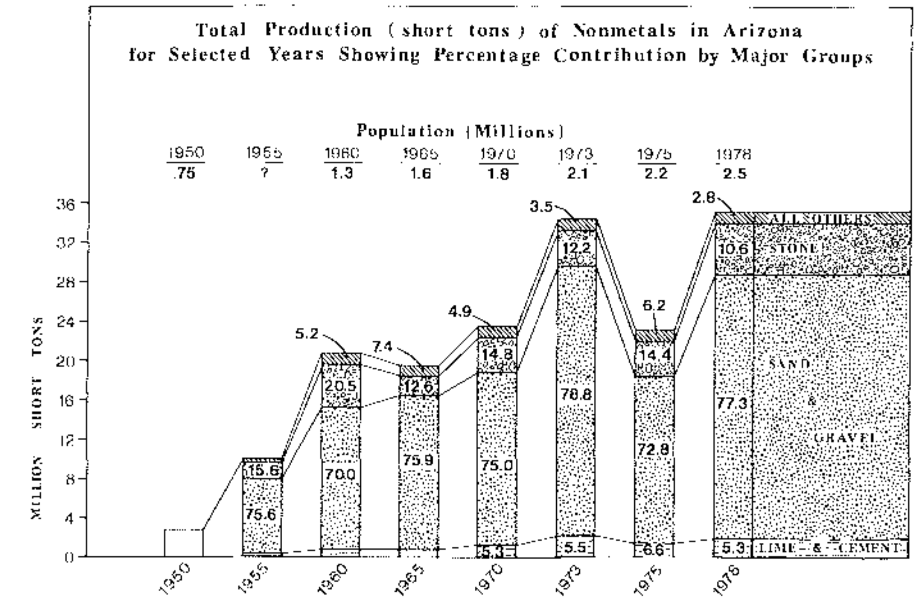


Figure 2*, *IM.* Total production (short tons) of industrial minerals in Arizona for selected years showing percentage contribution by major groups.

During 1978, in Arizona, we had a record of 153 sand and gravel deposits that supplied 133 plants. In contrast, there are but two cement plants. It is cheaper to have a nearby source of aggregate and bring the cement to it. Sand and gravel operations tend to stay as close to consuming centers as possible because it costs a lot to move this bulk around. Hopefully, our planners will not lose sight of this basic fact.

Stone

This group is quite diverse and embraces all of the rock types that are either crushed or quarried as building stone. Stone includes marble crushed for poultry grit and swimming pool plaster, as well as the excellent flagstone of the Plateau country. This flagstone is noted for its durability and capability of splitting into slabs of even thickness. The formation is the Coconino Sandstone that originally was deposited as sand dunes about 250 million years ago. This stone is shipped to many parts of the U.S.

Cinders

Cinders are volcanic ejecta that commonly occur in the form of cinder cones. Sunset Crater near Flagstaff is such a feature. In northern Arizona, in parts of the Plateau region, cinder cones are numerous and frequently quarried for use as railroad ballast, highway aggregate, dirt road surfacing and for other purposes. The red hue in many of the paved highways is imparted by reddish cinders. Cinders are widely used in northern Arizona in lieu of scarce, good quality gravel. Both red and black cinders are trucked to the Phoenix area block plants that manufacture cinder block.

continued on p. 10

AVERAGE VALUES (Short Ton) of SELECTED ARIZONA NONMETAL COMMODITIES

AV. VALUE/S T ($)	COMMODITY GROUPS
2000-3000	ZEOLITE (Chabazite)
600-800	ASBESTOS
80-100	FLUORSPAR (Acid grade)
40-60	CEMENT (Portland)
30-50	QUICKLIME
25-35	MICA
20-30	FLAGSTONE
15-20	SALT
12-18	FELDSPAR
12-15	CLAY (Montmorillonite), PERLITE, SPECIAL SAND, MARBLE (Crushed)
4-6	GYPSUM
3-4	STONE (Crushed)
2-3	SAND, GRAVEL, CLAY (Brick), CINDERS

Figure 3, *IM.* Average values (short tons) of selected Arizona industrial mineral commodities.

GEOLOGIC HAZARDS AND CONSTRAINTS New Research Effort in Arizona

by Susan M. DuBois

Geologic hazards, geologic constraints, engineering geology and other terms are variously used to embrace geologic processes, materials or conditions which may adversely impact human beings and their property or activities (see Figure 1). Discrete application of terminology to observed situations is highly desirable, but often difficult, due to the general confusion and ambiguities generated by so many "catch" words used by persons with different interests (for example, geologists, planners, engineers, developers, teachers, politicians, lobbyists, insurance agents and individual citizens). Therefore, it has become necessary to make the following distinctions:

A. Physical, Chemical and Biological Hazards

Geologic hazards can frequently encompass all of the above categories. However, geologic hazards which are the most easily-observed, mapped and predicted, as well as the most potentially damaging, often pose a direct physical threat, i.e., rushing water, landsliding, seismic shaking, erupting volcano, etc. In contrast, groundwater contamination and resulting human illness are examples of complex problems whose solutions cross many areas of expertise, geology being only one aspect.

B. Natural and Man-Induced Hazards

All geologic hazards by definition involve man's presence. A landslide is not a hazard unless it threatens life or property. However, a landslide can be induced or promoted by human activities, such as, excavating the toe of a slope during road building or watering a lawn on a steep hill. Some hazards are almost exclusively due to human actions (for example, cracked foundations caused by poor choices of fill materials or poor compaction procedures during construction). Dam failure, due to construction error, is a more severe example of man-caused hazards.

C. Hazards and Problems

The distinction between what is a problem and what is a hazard is relative between the extremes of merely being a nuisance and potentially causing death. Caliche buildup in topsoil presents a problem and increased cost in excavation procedures, but does not threaten life and property *per se.* However, a layer of caliche beneath a home may serve as a barrier to water drainage, causing ponding and possible flooding or cracking inside the house. This latter instance is indeed a potential hazard, although probably not life-threatening.

Recently, the Bureau initiated a study of natural processes, materials and conditions in Arizona which physically have the potential for causing loss of life, property damage, and increased cost to taxpayers in the form of disaster relief or continuous maintenance and repair. The emphasis is not, therefore, placed on possible adverse chemical-biological reactions (i.e., water quality, landfill leaching, naturally-radioactive deposits, etc.), nor on engineering designs, construction procedures or materials selected by man. Obviously, indirect effects induced by man cannot be completely eliminated from our research because of the basic relationship that exists between all human endeavors and the earth.

The following subjects will be researched:

1. Hydrologic hazards (flashflooding, bank erosion, floodplain inundation, sheetflooding);
2. Mass movement (rockfalls, slides, debris flows, avalanches, creep, slump);
3. Subsidence and/or collapse (from fluid withdrawal, solution weathering, lava tube caving, mining, earthquakes);
4. Earthquakes (maximum historical intensities, frequencies, tectonic significance, epicenter locations);
5. Volcanic hazards (lava flows, airborne ash, mudflows); and
6. Foundation problems (expansive soils, caliche, collapsing soils).

Arizona's neighbor state, California, commonly experiences a variety of disasters associated with earthquakes, landslides, floods and severe coastal erosion. These events have been widely publicized. Past death tolls, property loss and tax burdens have induced modifications to insurance policies, zoning regulations and state laws. Increased public awareness has also resulted from court action involving personal losses from the impact of various geologic hazards.

Population in Arizona (about 2.7 million) has increased sixfold since 1940. Business and industry are also rapidly expanding throughout the Sun Belt; therefore, knowledge of geologic hazards and associated land use problems becomes increasingly significant. Urban development has spread across the floodplains, "dry" washes, and into the mountain foothills surrounding Phoenix, Tucson and other communities in the state.

Seasonal flooding and associated hydrologic processes have caused loss of life and property throughout the state. Rocksliding, slumping and creep are problems in both northern and southern Arizona. Cracking of foundations, roads and utility lines has been reported from residential developments in Yuma, Tucson, Phoenix, Flagstaff and several other population centers. Two limestone paleokarst surfaces resulting in surface cracks and enlarged subsurface fractures in the Colorado Plateau physiographic province, have also caused reservoir leakage.

Though not widely known, continuing salt solution in northern Arizona has caused large sinkholes and collapse features. Subsidence and related earth fissures (some with vertical offset) have occurred in a few of the heavily-pumped basins of southern Arizona, most notably in the Eloy-Picacho region southeast of Phoenix.

The largest historical earthquake known to have caused widespread damage in Arizona occurred May 3, 1887. A fault with a 3 m normal displacement and over 50 km in length formed just south of the Arizona border in the San Bernardino Valley of Sonora. This earthquake (estimated magnitude 7.2) resulted in rockfalls as far north as Phoenix, building damage as far north as Tucson, and extensive ground failure and liquefaction in the extreme southeast portion of the state. Some of the state's seismicity is doubtlessly associated with the San Francisco volcanic field, north of Flagstaff. One of these volcanoes, Sunset Crater, last erupted in 1065 A.D.

At the present time, recurrence intervals for hazardous events have not been adequately estimated. Very little research has been conducted on potential seismic and volcanic hazards in Arizona. The possibility that a similar, large earthquake might again occur in northern Sonora or north of the border, in Arizona, is of major concern to agencies responsible for emergency response plans. No estimates of potential damage from mass movements exist. The occurrence of expansive and collapsing soils and other problem soils have not yet been assessed on a statewide basis. Differential compaction and surface fissuring, because of fluid withdrawal, is expected to become an increasingly-damaging phenomenon throughout rapidly-growing populated areas of the Basin and Range Province.

Consequently, the Arizona Bureau of Geology and Mineral Technology, through a cooperative agreement with the U.S. Geological Survey, is making a regional assessment of geologic hazards and constraints in the State of Arizona.* In addition, a photo file is being established to visually document historical geologic hazards. A series of susceptibility maps (1:1,000,000 scale) will be produced, as well as a bibliography of Arizona hazards and related information. These maps will aid in focusing attention on significant geologic hazards problems in Arizona. The series should also prove useful to regional planners, consultants and private citizens who presently do not have easy access to general information on this subject. Since the frequency of hazardous events cannot yet be estimated for most hazards and since the property values and number of lives potentially affected by a particular hazard in various regions are unknown, the map series will *not* designate risk parameters. Rather, they will be designed to indicate the presence of and/or susceptibility to a specific problem, as determined from factors, such as, topography, type and thickness of material, geologic structure and meteorological data.

Information and inquiries concerning geologic hazards should be addressed to the principal investigator of this study, Susan M. DuBois, Geologist, Bureau of Geology and Mineral Technology, Geological Survey Branch, 845 N. Park Ave., Tucson, AZ 85719.

*Compilation of existing data is underway. Economic loss figures will be solicited from various governmental agencies involved in disaster relief or general maintenance of facilities susceptible to damage from geologic factors.

Figure 1

GLOSSARY

Engineering Geology*— The application of geologic data, techniques and principles to the study of naturally occurring rock and soil materials or ground water for the purpose of assuring that geologic factors affecting the location, planning, design, construction, operation and maintenance of engineering structures, and the development of ground water resources, are properly recognized and adequately interpreted, utilized and presented for use.

Environmental Geology*— The collection, analysis and application of geologic data and principles to problems created by human occupancy and use of the physical environment. It involves studies of hydrogeology, topography, engineering geology and economic geology, and is concerned with earth processes, earth resources and engineering properties of earth materials. *For example, construction of buildings and transportation facilities or safe disposal of solid and liquid wastes.*

Geologic Constraint — A geologic factor which presents problems associated with human endeavors, not necessarily insurmountable; usually involves increased costs to engineering projects, delays in construction or development of alternative sites. *For example, poorly-drained soils for septic installations, steep slopes in residential construction, subsidence/fissuring from fluid withdrawal damaging a highway.*

Geologic Hazard*— A naturally occurring or man-made geologic condition or phenomenon that presents a risk or is a potential danger to life and property. *For example, landslides, earthquakes, floods.*

Hazard Mitigation — Measures implemented to lessen the severity or likelihood of loss or harm. *For example, flood-control dams, levees, retaining walls, zoning regulations, disaster relief funds, earthquake designs for buildings.*

Risk — Possibility, or more often, *probability* of loss or peril from a given hazard; usually *quantitatively* expressed. *For example, a 10% chance in 50 years that loss of life will occur due to landsliding.*

Susceptibility — Capability in various areas of exhibiting specified hazardous processes, materials or conditions; usually *qualitatively* expressed. *For example, low, moderate or high.*

*These definitions were taken from the American Geological Institute's *Glossary of Geology* (1977)

NEW PUBLICATION

Studies in Western Arizona, Arizona Geological Society Digest XII, editors Judith P. Jenney and Claudia Stone, 1980, 338p.

Compilation of 16 articles on geochronology, structural geology, stratigraphy, aeromagnetics, areal geology and geomorphology of western Arizona; includes papers on Laramide thrusting in westcentral and southeastern Arizona, the geochronology and listric faulting in the Vulture Mountains; Precambrian geology of the Bradshaw and Hualapai Mountains; over 170 previously unpublished K-AR dates from southwestern Arizona and adjacent areas; an index of theses and dissertations on Arizona geology, completed at U of A, ASU and NAU through 1979.

Digest XII may be obtained from Arizona Geological Society Publications, P.O. Box 40952, Tucson, Arizona 85717. Cost is $15.00, postage included.

Publications in Progress

Geologic Hazards Bibliography
Laramide Map (Arizona)
Molybdenum Map (Arizona)

On File and Available for Review

Abstracts on Arizona Geology
Graduate Theses on Arizona Geology*
1979 Theses from Arizona Universities*
Open File Reports: USGS, DOE, BGMT

*includes author, title, keyword index

Uranium Compilation Progresses

The Bureau's DOE-funded compilation of all radioactive occurrences in Arizona is in progress. Department of Energy files are the central data bank for the preliminary listing thus far of about 1,000 occurrences, including all known past producers of uranium in the State. The final report is now envisioned as containing a broad discussion of uranium host rocks, a county-by-county listing of occurrences containing information on location, mine development, past uranium production, site geology, radioactivity, literature references, and a series of maps plotting all known occurrences. A short synopsis of recent exploration activities will be included. Compilation is scheduled to be completed by October, 1980, and the results will be published in early 1981.

We would appreciate that all interested parties with knowledge of Arizona uranium occurrences or past mining activity, which may not already be part of the public record, to contact the Bureau as soon as possible in order to make the compilation more complete. Please contact Robert Scarborough or Wes Peirce at the Bureau of Geology and Mineral Technology.

NATIONAL/REGIONAL EVENTS

U.S. Geological Survey — Conference on Evaluation of Regional Seismic Hazards and Risk, Santa Fe, NM, August 25-27, 1980

Geothermal Resources Council — Annual Meeting, Salt Lake City, UT, September 9-11, 1980

American Mining Congress — Mining Convention, San Francisco, CA, September 21-24, 1980

American Institute of Professional Geologists — Annual Meeting, Mobile, AL, September 24-27, 1980

Association of Earth Science Editors — Annual Meeting, Halifax, NS, October 19-22, 1980

Los Alamos Scientific Laboratory — Hot Dry Rock Geothermal Energy, Annual Meeting, Los Alamos, NM, October 28-29, 1980

Society of Exploration of Geophysists — 50th Annual Meeting, Houston, TX, November 16-20, 1980

Geological Society of America — Annual Meeting with Associated Societies (Paleontological Society, Society of Economic Geologists, Mineralogical Society of America, Geoscience Information Society, Geochemical Society, National Association of Geology Teachers, Cushman Foundation), Atlanta, GA, November 17-20, 1980

LIST OF AVAILABLE PUBLICATIONS

SPECIAL PAPERS

1. Late Cenozoic geology of the White Mountains, Arizona. R.K. Merrill and T.L. Péwé (1977)	$4.50
2. Guidebook to the geology of central Arizona. Edited by D.M. Burt and T.L. Péwé (1978)	6.00

BULLETINS

137. Arizona lode gold mines and gold mining. E.D. Wilson, J.B. Cunningham and G.M. Butler (1934)	2.75
162. Pegmatite deposits of the White Picacho district, Maricopa and Yavapai counties, Arizona. R.H. Jahns (1952)	1.25
164. Exploration and development of small mines. H.E. Krumlauf (Revised 1966)	.25
165. One hundred Arizona minerals. R.T. Moore (1955)	.75
167. Some rare-earth mineral deposits in Mohave County, Arizona. E.W. Heinrich (1960)	.50
168. Gold placers and placering in Arizona. E.D. Wilson and others (1961)	2.00
171. A resume of the geology of Arizona. E.D. Wilson (1962)	1.50
172. The use of compressed air in small mines. H.E. Krumlauf (1963)	.50
173. Bibliography of the geology and mineral resources of Arizona, 1848-1964. R.T. Moore and E.D. Wilson (1965)	3.00
174. Guidebook 1 – highways of Arizona, U.S. Highway 666. E.D. Wilson (1965)	.50
175. Field tests for the common mineral elements. G.H. Roseveare (1966)	1.00
176. Geologic guidebook 2 – highways of Arizona, Arizona Highways 77 and 177. H.W. Peirce (1967)	1.25
177. Mineral deposits of the Fort Apache Indian Reservation, Arizona. R.T. Moore (1968)	1.25
179. Mineral deposits of the Gila River Indian Reservation, Arizona. E.D. Wilson (1969)	1.00
180. Mineral and water resources of Arizona (1969)	4.50
182. Coal, oil, natural gas, helium and uranium in Arizona. H.W. Peirce, S.B. Keith and J.C. Wilt (1970)	4.50
183. Geological guidebook 3 – highways of Arizona, Arizona Highways 85, 86 and 386. S.B. Keith (1971)	1.00
184. Geologic guidebook 4 – highways of Arizona, Arizona Highways 87, 88 and 188. C. Royse, M. Sheridan & H. Peirce (1971)	.75
185. Arizona well information. H.W. Peirce and J.R. Scurlock (1972)	2.00
186. Geology of the Virgin and Beaverdam Mountains, Arizona. R.T. Moore (1972)	2.00
187. Index of mining properties in Cochise County, Arizona. S.B. Keith (1973)	1.00
188. The mineral industry of Arizona in 1971. (Amended 1974)	.15
189. Index of mining properties in Pima County, Arizona. S.B. Keith (1974)	2.00
190. Bibliography of the geology and mineral resources of Arizona, 1965-1970. J.S. Vuich and J.C. Wilt (1974)	2.00
191. Index of mining properties in Santa Cruz County, Arizona. S.B. Keith (1975)	1.50
192. Index of mining properties in Yuma County, Arizona. S.B. Keith (1978)	3.00

CIRCULARS

16. Strata-bound sulfide deposits and suggestions for exploration in Arizona. J.S. Vuich (1974)	.50
17. Utilization of municipal waste water for froth flotation of copper and molybdenum sulfides. W. Fisher & S. Rudy (1976)	.75
	.75
18. Chemical analyses of coal samples from the Black Mesa field, Arizona. R.T. Moore and others (1977)	.50
19. A survey of uranium favorability of Paleozoic rocks in the Mogollon rim and slope region, east-central Arizona. H.W. Peirce and others. (1977)	1.75
20. Geology of the Socorro Peak area, western Harquahala Mountains. R.J. Varga (1977)	1.00

OPEN FILE REPORT

A study of uranium favorability of Cenozoic sedimentary rocks, basin and range province, Arizona: Part I. General geology & chronology of pre-late Miocene-Cenozoic sedimentary rocks. R.B. Scarborough and J.C. Wilt, Report No. 79-1429 (1979)	12.00 (14.00 by mail)

MAPS

All maps are printed in color at a scale of approximately 16 miles/inch (1:1,000,000) unless otherwise specified. Mail orders will be accepted for folded maps only.

1. Base map of Arizona. Not in color	.25
3. County geologic map series, Printed in color, scale approximately six miles/inch (1:375,000).	
3-1 Cochise County (1959)	.75
3-2 Coconino County (1960)	1.00
3-3 Gila County (1960)	.75
3-4 Graham-Greenlee Counties (1958)	.75
3-5 Maricopa County (1957)	.75
3-6 Mohave County (1959)	.75
3-7 Navajo-Apache Counties (1960)	1.00
3-8 Pima-Santa Cruz Counties (1960)	.75
3-9 Pinal County (1959)	.75
3-10 Yavapai County (1958)	.75
3-11 Yuma County (1960)	.75
4. Metallic mineral occurrence maps.	
4-1 Map of known nonferrous base and metal mineral occurrences in Arizona (1969)	.75
4-2 Map of known metallic mineral occurrences in Arizona (excluding base and precious metals) (1969)	.75
5. Map of known nonmetallic mineral occurrences in Arizona (1965)	.75
6. Map and index of Arizona mining districts (1961)	.75
7. Geologic cross sections of Arizona. Printed in color, at a scale of approximately three miles/inch. A free index of the cross sections, printed in color on the base map of Arizona, will be included with the purchase of any of the following maps:	
7-1 Sheet one, sections 1, 2 and 3 (1962)	1.00
7-2 Sheet two, sections 4, 5 and 6 (1962)	1.00
7-3 Sheet three, sections 7 and 8 (1962)	1.00
8. Map of outcrops of Precambrian rocks in Arizona (1962)	.50*
9. Map of outcrops of Paleozoic and Mesozoic rocks in Arizona (1962)	.50
10. Map of outcrops of Laramide (Cretaceous-Tertiary) rocks in Arizona (1962)	.50*
11. Map of outcrops of Tertiary and Quaternary igneous rocks in Arizona (1962)	.50
12. Map of Arizona showing principal power and transportation facilities (1963)	.50
13. Geologic map of Arizona. Printed in color, scale approximately eight miles/inch (1:500,000). (1969)	3.00
14. Geologic map & cross sections of Arizona. Printed in color, scale approximately 40 miles/inch (1:2,500,000). (1977)	.25
15. Geothermal energy resources of Arizona, Map No. 1 (1978)	1.75

FOLIO SERIES

1. Environmental Geology of the McDowell Mountains area, Maricopa County, Arizona. G.E. Christenson, D.G. Welsch and T.L. Péwé. Printed in color at a scale of 1:24,000.	
Map GI-1-A Geology (1978) Map GI-1-B Landforms (1979)	2.50
Map GI-1-C Land Slopes (1979)	1.25
Map GI-1-D Caliche (1979)	1.25
Map GI-1-E Ground Water (1979)	1.25
Map GI-1-F Material Resources (1979)	1.25
Map GI-1-G Geologic Hazards (1979)	1.25
Map GI-1-H Excavation Conditions (1979)	1.25
Map GI-1-I Waste Disposal (1980)	1.25
Map GI-1-J Construction Conditions (1980)	1.25

The entire map series of the McDowell Folio is available for $10.00

GEOLOGIC MAP SET

NOTE: A complete set of maps published by the Bureau is available for $27.00 (excluding maps #1, #13 and the Folio Series). The set contains 23 maps, 12 filler sheets and one binder.

*Temporarily out of print

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MILS PROJECT

A grant has been awarded to the Arizona Department of Mineral Resources by the U.S. Bureau of Mines to complete an inventory of mineral prospects, operating mines, mills, smelters, refiners, past and present producers of metals, non-metals, sand and gravel, coal and geothermal resources. The resultant data are being entered into MILS (Mineral Industry Location System), which is part of a larger data system known as MAS (Minerals Availability System).

The subcontractor, Coe and Van Loo Engineering Company of Phoenix, is preparing data entry forms and plotting locations on the county highway series base maps (one inch on the map equals two miles on the ground). The commodity produced, current status, type of operation, and other information are being recorded for each location. Coe and Van Loo is now working on Apache, Coconino, Gila, Graham, Greenlee, Maricopa, Navajo, Pinal and Yavapai Counties. Completion date for the project is March 1981.

Last year the U.S. Bureau of Mines funded a project for the other Arizona counties: Coe and Van Loo completed Santa Cruz and Mohave Counties; Wallaby Enterprises of Tucson did Yuma, Cochise and Pima Counties. These data and maps are currently available. For more information about the project status, please contact Mr. John Jett, Director, Department of Mineral Resources, Mineral Building, Fairgrounds, Phoenix, AZ 85007.

State Mapping Advisory Committee

Governor Babbitt has appointed Jacqueline Rich to chair the State Mapping Advisory Committee for a one-year term. Ms. Rich is Environmental Policy Program Manager in the Office of Economic Planning and Development. The State Mapping Advisory Committee (SMAC) is one of the functional work units of the State Data Coordination Network, which is chaired by Ms. Terry Murray, the Planning Director in the Office of Economic Planning and Development.

The main purpose of the SMAC is to provide state input to the U.S. Geological Survey (USGS) regarding topographic mapping priorities. The USGS has the long-term responsibility of preparing accurate topographic maps for the entire nation. In the past, the USGS has determined priorities for new mapping by asking Federal agencies to suggest which areas (quadrangles) were most important to them. Now the State has a say, too.

Topographic maps show the configuration of the land surface by means of contour lines. In addition, the maps show many other phenomena, including the location of rivers or washes, canals, roads, railroads, power lines, section and township lines, elevations of selected points, bench marks, prospect pits, mines, lakes, and residences. The USGS is actively producing topographic quadrangle maps at a scale of 1:24,000 (one inch on the map equals 2,000 feet on the ground). These maps may be purchased from the Arizona State Land Department, National Cartographic Information Center affiliate office for Arizona (1624 West Adams, Phoenix, AZ 85007). The Land Department has an index map that shows which quadrangle maps are available and also a map that shows the status of topographic maps currently being prepared by the USGS.

SMAC also provides feedback and recommendations to the USGS about the USGS topographic mapping and air photo programs, reviews and comments on new mapping programs, and serves as an inter-agency advisory committee for state projects that include mapping and related work.

Federal agency representatives and other interested persons and agencies are invited to participate in SMAC meetings. For additional information, please contact Ms. Jacqueline Rich, Office of Economic Planning and Development, 1700 West Washington, Fourth Floor, Phoenix, AZ 85007.

AGS SPRING FIELD TRIP

by Larry D. Fellows

Approximately 110 Arizona Geological Society members and guests toured the Whipple Mountains, on the west side of the Colorado River in California north of Parker, Arizona, and the Buckskin Mountains, east of the Colorado River in northern Yuma county, March 29-30. The trip, coordinated by Tom Heidrick of Gulf Mineral Resources Co., started in Parker, Arizona. The California portion was led by Gregory A. Davis, J. Lawford Anderson, and Eric G. Frost, all from the University of Southern California in Los Angeles. Tom Heidrick and Joe Wilkins (Gulf Mineral Resources Co.), led the Arizona portion.

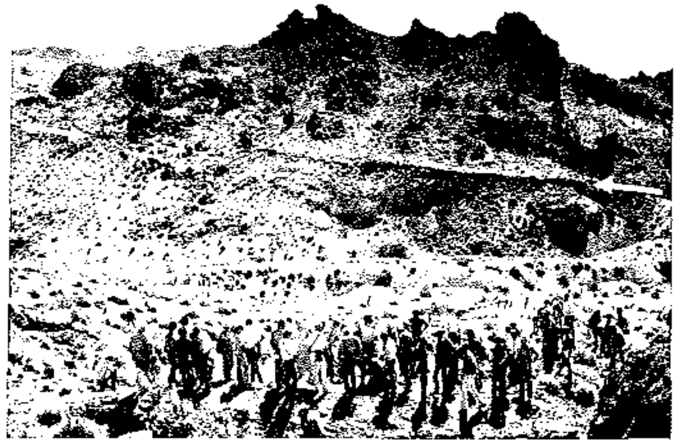


Figure 1, *AGS Trip.* Detachment fault in Whipple Mountains (Stop 1 on Field Trip). Fault dips toward southwest (right). Upper plate rocks moved northeast (right to left) across lower plate units along a sub-horizontal detachment surface that has since been warped.

Figure 2, *AGS Trip.* Geologists standing on striated, polished detachment surface, which dips toward the right (southwest). Photograph taken at Stop 2 (Whipple Mountains), but at a different locality than that shown in Fig. 1.

Exposed in the Whipple-Buckskin mountains region is a major subhorizontal detachment fault that divides the terrain into two major plates. On the basis of field relations in the Whipple Mountains, the detachment faulting is determined to have begun approximately 18 million years before present and to have ended 13-15 million years ago. Upper plate rocks moved toward the northeast (N 50° + 10° E) across the lower plate along a detachment surface (Figs. 1 and 2). Upper plate rocks include

continued on p. 12

MINE SAFETY AND HEALTH PROGRAM

by William H. Dresher

The University of Arizona College of Mines and the Arizona Center for Occupational Health and Safety (ACOSH) have established a joint mine safety and health training program under the auspices of the National Institute for Occupational Safety and Health (NIOSH). The program, which is titled the Mine Safety and Health program, is the first of its kind in the United States and represents a new approach in mining schools and colleges to education and research in the area of mineral industry health and safety. The program is directed by Professor Jay C. Dotson of the Department of Mining and Geological Engineering and has ACOSH industrial hygienist Dr. James O. Jackson as its assistant director. Under the program Dr. Jackson lectures on occupational health and safety as a full time faculty member of the College of Mines.

Dr. James O. Jackson, Assistant Director of the Mine Safety and Health Program

Mining, and to some extent, mineral processing and smelting have been inherently dangerous occupations. Heavy equipment is involved, often toxic chemicals are used and the workplace can be both dusty and noisy. Because of past problems, mainly in underground coal mines, but also in noncoal and surface mines, the federal government has promulgated regulations to guard against occupational safety and health hazards in the mineral industry. One such regulation, for example, requires that all employees with jobs in a mine must undergo at least a minimum amount of safety and health training before being permitted to work in the mine. As a consequence of the collective interest in safety and health matters in mining, milling and smelting operations, there has developed a need for formal training of both labor and management in this industry. The University of Arizona Mine Safety and Health Program is designed to meet the need for providing the safety and health component of the mining and metallurgical engineering undergraduate curriculum, as well as to provide the opportunity for post graduate instruction and training to management, engineering or health and safety personnel who are employed in the mineral industry or to graduates from the undergraduate programs who wish to specialize and become mine safety and health professionals.

The Mine Safety and Health program is being developed in conjunction with safety and health personnel from local industry and is being integrated with the ACOSH continuing education program in industrial hygiene and safety. During the past semester, for example, courses were presented on the campus of the University of Arizona in Mine Atmosphere Control and Safety, Mine Environments, Man and Machine: Safety Interaction and Occupational Hearing Conservation. Essentially the College intends to develop continuing education programs, specifically designed for mining safety and health professionals which will be offered in accordance with perceived community and geographical area needs, as well as with NIOSH continuing education guidelines and requirements. The most important effort during the coming year will be the design and development of mine safety and health core curriculum. Besides the determination of the best possible approach to the education and granting of degrees in the safety and health aspects of mining, the course control and program direction will be established.

Consideration is being given to any approach that is feasible within the structure of the University in deciding the best method for academic training in the Core Program. Examples could include: (1) Expansion of current health and safety courses in the College of Mines, coupled with a second M.S. degree program in Health Related Professions (HRP); (2) Establishment of a minor in safety and health for the Mining engineering undergraduate and graduate students; and (3) Development of a mining track in HRP.

Specific courses will be determined as a result of the needs assessment and will probably be somewhat flexible during these initial stages. Existing coursework in the various ACOSH Core Programs will be a beginning on which the specific mining safety and health program will be built. The courses could include: Biostatistics, Hazardous Materials, Human Factors in Complex Systems, Industrial Hygiene Instrumentation and Analysis, Industrial Toxicology, Introduction to Epidemiology, Occupational Safety and Health, Physical Exposures, Safety and Institutional Policy Analysis, Safety Law, and Safety Management. At least one new course will be offered during the Fall 1980 semester as well as in the Spring of 1981.

In addition to the classroom program, the University has an experimental mine just south of Tucson. This mine will be used when appropriate for teaching and laboratory purposes. For example, students would be able to evaluate mine ventilation systems and their effectiveness at reducing and/or eliminating toxic contaminants in various locations under differing mine operation conditions.

Research is a vital component of any graduate program, and research program areas for mine safety and health are currently being examined and explored. One project, sponsored by the U.S. Bureau of Mines, involving the identification and quantitative measurement of gases resulting from the use of explosives in underground mines, is already underway at the University's experimental mine. The emphasis remains on providing effective learning and growth experience for students and on interaction with other ACOSH Programs. Proposals will be prepared and submitted as and where appropriate, particularly where graduate students can be involved. Several research areas under possible consideration are: Particle Size Profiles in Various Mining Operation: Qualitative and Quantitative Identification of Non-CO, CH_4, and NO_x Gaseous and Vaporous Components of Mine Atmospheres; Application of Scrubbing Devices for Mining Machines; Optimization of Water Spraying Techniques; Surface Mining Dust Control Procedures; Polynuclear Aromatic Hydrocarbon Sampling; and Analytical Procedures in Mining.

In a very real sense, the Program in Mine Safety and Health has already been implemented. Support exists throughout the University, courses are available that provide needed didactic strength, and now specific courses are to be presented. Program evaluation and review will occur frequently, particularly in the next fiscal year, as the Program is being developed.

For more information concerning the University of Arizona Mine Safety and Health program, contact: Professor Jay C. Dotson, Department of Mining and Geological Engineering, University of Arizona, Tucson, AZ. 85721.

Production History of Nonmetals in Arizona 1895-1978

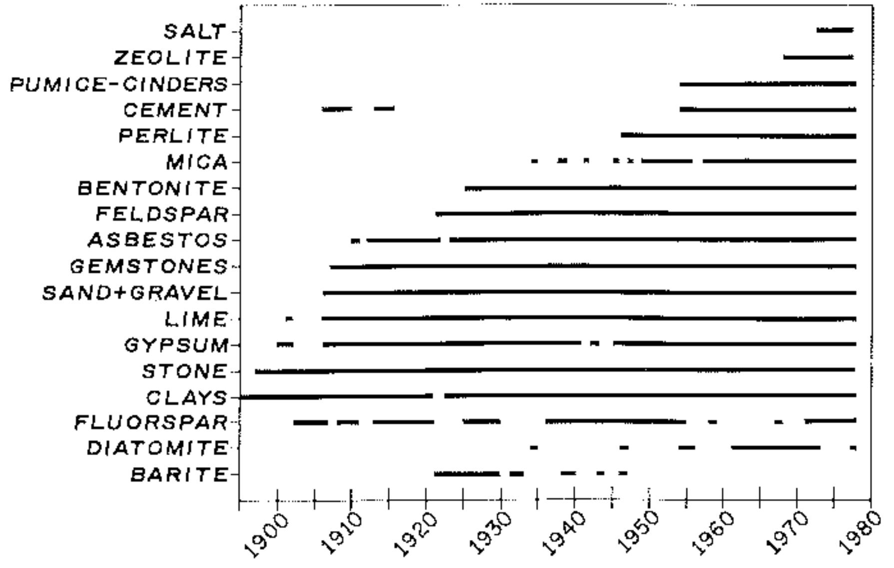


Figure 4, *IM.* History of industrial minerals produced in Arizona, 1895-1978.

*Figures 2-4: Basic data compiled by Solomon Toweh, University of Arizona Graduate Student.

Industrial Minerals continued

Gemstones

Although it is difficult to assign a credible monetary value, it is thought that Arizona is the U.S. leader in the sale of gemstones: Estimates range to about $5 million, the largest part of which would be assigned to turquoise removed under contract from a few of the State's large copper mines. Certainly, the beautiful 200 million year old petrified wood of northern Arizona is a significant part of the commerce in gemstones.

Special Clay

Special clay is to be distinguished from the more common clays utilized in the making of red brick. A unique clay has been mined on the Plateau in southern Apache County since the 1920's. It is of sufficient value to warrant the removal of 80 feet or more of overburden. Technically, the clay is a low-swelling montmorillonite that has been used in making beauty preparations, refining and decolorizing mineral and edible oils, the making of catalysts for refining petroleum, and in desiccants. The material has been shipped all over the world. Its origin is attributed to the alteration of vitric ash beds included within the five million year old Bidahochi Formation. There is much interest in finding additional resources of this type in Arizona, but thus far the results have not been encouraging. Deposits that are totally buried may exist but, if so, would be difficult to find.

Salt

Arizona's newest IM industry is the production of common salt, or halite, near Phoenix. In 1968, a salt exploration hole drilled west of Phoenix encountered salt 880 feet beneath a cotton field. This formation is massive rock salt estimated to be about 10,000 feet thick and to occupy about 15 cubic miles of the subsurface. Water is pumped into the salt and the resulting brine is evaporated in surface ponds by the Arizona sun. Uses include water softening, hide curing and cattle feed.

Adjacent to the salt works is a subsurface storage project that utilizes space created by controlled solutioning of salt. Both propane and butane are stored and removed by an automated system that services a nearby railroad spur. Excess butane from California petroleum refineries is stored here in summer and returned and added to winter gasoline supplies in order to enhance cold weather starting. It is cheaper to store propane and butane in Arizona salt than in California where there are no recognized massive salt deposits. There is another salt storage project on the Plateau in the Holbrook Basin salt deposit (see map, p. 1). Another is planned for the Red Lake deposit of northwestern Arizona where Southwest Gas plans to store natural gas to supply peak demand in California.

Zeolite

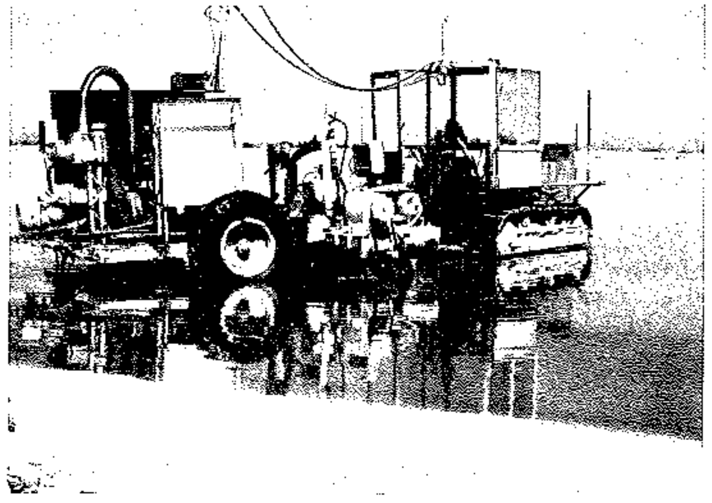
Not only is the production of natural zeolite relatively new in Arizona (Fig. 4), it is the first operation of its kind in the U.S. *Zeolite* is a large family of similar mineral species that vary slightly, but importantly, in their specific physical-chemical attributes. Technological need, combined with the belated recognition that *large* deposits of high-grade zeolite occur naturally, sparked exploration throughout the U.S. The use of natural zeolites promises to rise dramatically during the coming decade. Emphasis is placed on *natural* because in the past these minerals have been produced synthetically. Fundamentally, zeolites are used in making molecular sieves capable of selectively removing certain molecular mixtures based on the size and shape of molecules. As an example, one use for Arizona chabazite is the separation of hydrogen sulfide from natural gas. Like the *special clay*, zeolite minerals tend to represent an alteration product derived from vitric ash deposits. Many of the zeolite minerals are known to occur in Arizona's Basin and Range Province.

THE FUTURE

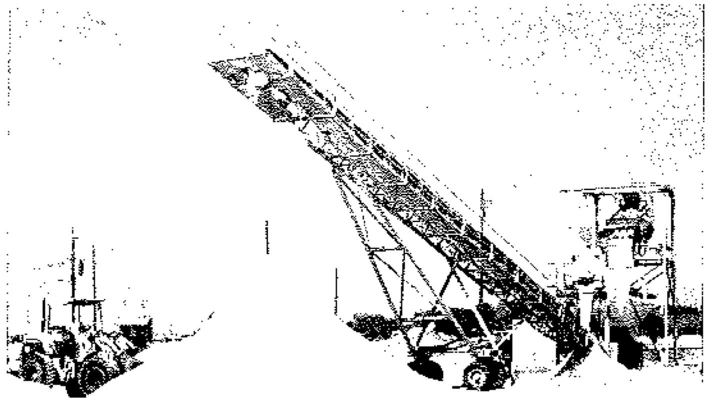
Arizona, like a magnet, attracts people. Population growth seems inevitable, as does the industrial growth that must occur if people are to find employment. Whether or not there will be significant expansion in basic IM industries depends upon growth rate. Arizona has the potential for development of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

Because of geologic variety and complexity, Arizona's major mineral production and remaining development potential is vested in the southwestern half of the State — the Basin and Range geologic province. Actually, many geologic mysteries remain; and, inherent in these are mineral resource discovery opportunities, opportunities that must be identified if the State and nation are to continue to have the basic ingredients that have come to be the foundations of modern civilization.

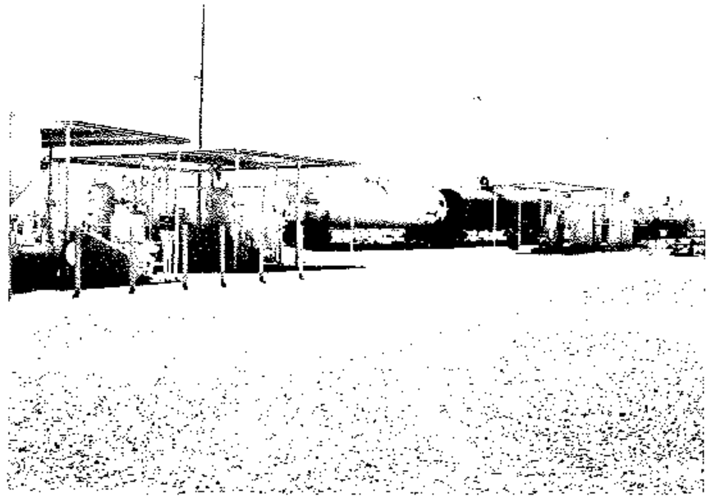
SOME ARIZONA INDUSTRIAL MINERAL OPERATIONS



Harvesting salt from an evaporation pond

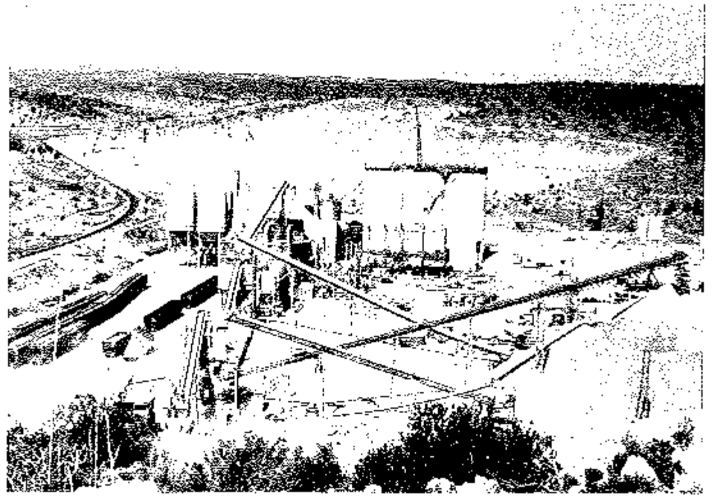


Salt washing and stacking

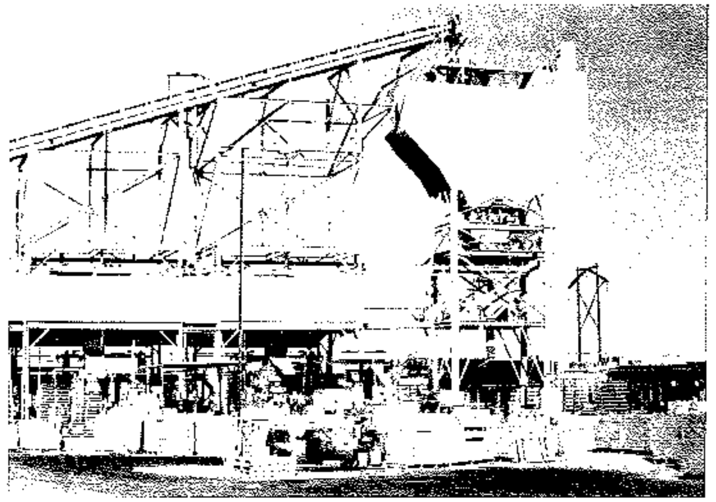


Propane-butane loading/unloading system. Products stored in a solution cavity washed out of salt

Stone yard. Flagstone is quarried from the Coconino Sandstone of northern Arizona



Lime plant of the Flintkote Company, U.S. Lime Division. Fuel on railroad cars is coal shipped from New Mexico



Block-making plant, Phoenix area

Photos: H.W. Peirce

ABSTRACTS

The following papers on Arizona geology were presented at the 33rd annual meeting of the Rocky Mountain Section, Geological Society of America, held in Ogden, Utah on May 16-17, 1980:

Volcanic Rocks of the Colorado Plateau Transition Zone, Northern Arizona.
Arney, Barbara; Goff, Fraser F.; Eddy, Andrea. Geosciences Division, Los Alamos Scientific Laboratory, Los Alamos, NM 87545

A Magnetically Defined Tectonic Feature across southern Arizona.
Klein, Douglas P., U.S.G.S., Denver Federal Center, Mail Stop 164, Box 25046, Denver, CO 80225

Plate Tectonics of the Ancestral Rocky Mountains.
Kluth, Charles F. and Coney, Peter J., Department of Geosciences, University of Arizona, Tucson, AZ 85721

Paleogeography and Tectonism at the Time of the Precambrian Cardenas Lavas, Eastern Grand Canyon, Arizona.
Lucchitta, Ivo, U.S.G.S., Flagstaff Field Center, 2255 North Gemini Drive, Flagstaff, AZ 86001; Hendricks, John D., U.S.G.S., Box 25046, MS 964, Denver, CO 80225

The Miocene Artillery and Chapin Wash Formations of West-central Arizona: Identification and Significance.
Lucchitta, Ivo, U.S.G.S., Flagstaff Field Center, 2255 North Gemini Drive, Flagstaff, AZ 86001; Suneson, Neil, Department of Geological Sciences, U.C., Santa Barbara, Santa Barbara, CA 93106

Future Subsidence along Salt Gila Aqueduct, AZ.
Prokopovich, N.P., Water and Power Resources Service, Mid-Pacific Region, Sacramento, CA 95825

Recognition and Monitoring of Rockfall Hazards at Selected National Park Service Sites in Arizona, New Mexico and Colorado.
Wachter, Bruce G., Department of Geosciences, University of Arizona, Tucson, AZ 85721; Rutenbeck, Todd, National Park Service, Western Archaeological Center, P.O. Box 41058, Tucson, AZ 85717

Breccia Pipes at Copper Creek, Arizona; Evidence for Multiple Stages of Hydrothermal Activity.
Walber, V.A., Phelps Dodge Corp., 3007 So. W.Temple, Salt Lake City, UT 84115

Arizona Molybdenum Minerals as Keys to Metallogenic Types.
Wilt, Jan Carol, Bureau of Geology, 845 N. Park Ave., Tucson, AZ 85719.

AGS trip continued

Tertiary sedimentary deposits of Miocene age that dip regionally toward the southwest. Because the upper plate rocks are cut by northwest-trending normal faults that merge into the detachment fault, the southwest dips are interpreted to represent rotation on listric normal faults. Although this trip focused on field observations in the Whipple and Buckskin Mountains, similar relationships are known to exist in the Dead, Sacramento, and Chemehuevi Mountains in California northwest of Parker and in the Mohave, Rawhide, Harcuvar and Harquahala Mountains in western Arizona.

Copper mineralization has occurred in both upper and lower plate rocks adjacent to the detachment surface at: (1) Copper Basin, California, (2) Planet, (3) Swansea, (4) the Copper Penny prospect near Swansea, and at other localities in Arizona.

The trip provided an excellent opportunity for one to observe a major, regional, sub-horizontal detachment fault complex and mineralization that is likely present in the subsurface in adjacent portions of California and Arizona and, perhaps, even in more distant parts of the State.

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