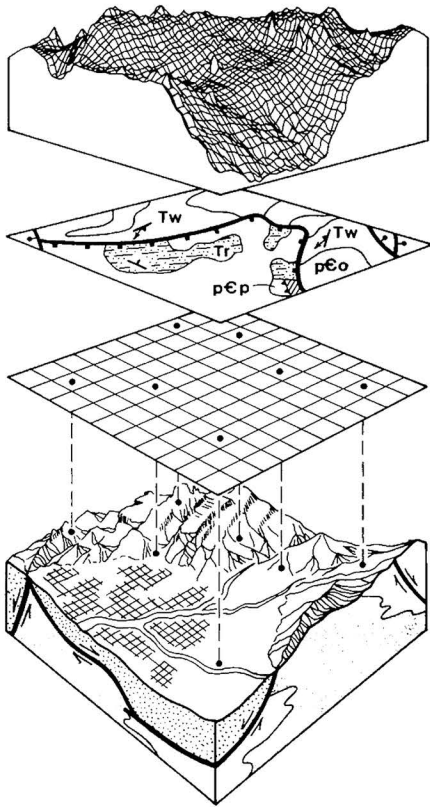


# FRONTIERS IN GEOLOGY AND ORE DEPOSITS OF ARIZONA AND THE SOUTHWEST

Arizona Geological Society and the University of Arizona 1986 Symposium



## FIELD TRIP GUIDEBOOK #6

### Industrial Mineral Deposits of Arizona

March 18-19, 1986

Leader: T. Eyde (GSA Resources, Inc.)

Coordinators: P. Wilkinson (Consultant) and E. Weiland (Consultant)



**ARIZONA GEOLOGICAL SOCIETY**  
TUCSON, ARIZONA

Cover preparation by Beverly Morgan, modified from J. Mehulka  
and P. Mirocha, AGS Digest Volume XVI



# ARIZONA GEOLOGICAL SOCIETY

P.O. BOX 40952, UNIVERSITY STATION  
TUCSON, ARIZONA 85719

To: Field Trip Participants

Welcome to Arizona and the 1986 Arizona Geological Society Symposium "Frontiers in Geology and Ore Deposits of Arizona and the Southwest." As field trip chairman I would like to wish you an enjoyable and informative conference and a worthwhile field trip experience.

The field trip committee set out many months ago to provide field exposure to a broad spectrum of geological disciplines. The results include trips to recent precious-metal discoveries, areas of new and developing stratigraphic and structure concepts, industrial mineral resources, lithologic features significant to the petroleum potential in the Southwest, geologic hazards in the community, and an opportunity to attend trips from previous Arizona Geological Society meetings. We hope you find your chosen field trip as exciting as we intended.

At this time of very limited support from industry, it is especially important to acknowledge the personal efforts of so many. I include in those the planning and follow through of the field trip committee, the many hours of preparation by the trip leaders, and the commitment of the trip coordinators to a smooth-running trip. A special thanks goes to Maggie Morris of the University of Arizona Conference Department for the transportation, lodging, and meal arrangements.

Please enjoy the Southwest and remember this week of field trips and meetings as a step toward the frontiers of the future.

Best regards,

Parry D. Willard  
Field Trip Chairman

## Field Trip Committee

Annon Cook  
Norm Lehman  
Beverly Morgan  
Jon Spencer  
Erick Weiland  
Joe Wilkins Jr.  
Jan Wilt

ITINERARY  
FIELD TRIP 6  
INDUSTRIAL MINERAL DEPOSITS OF ARIZONA

Leader: Ted Eyde (GSA Resources, Inc.)  
Coordinators: Pamela A. K. Wilkinson (Consultant) and Erick F. Weiland  
(Consultant)

Tuesday, March 18, 1986

7:30 am Depart from University of Arizona, front of Student Union  
8:30 am Stop 1. Feldman gypsum deposit  
9:30 am Stop 2. Dripping Springs chabazite deposit  
11:00 am Lunch\* Oak Flat picnic area, Tonto National Forest  
12:30 pm Stop 3. Superior perlite deposit  
3:00 pm Stop 4. Luke salt dome  
5:00 pm Arrive and check in at Rancho Grande Motel,\* Wickenburg,  
Ariz. (602-684-5445)  
6:30 pm Steak fry\* at Rancho Bar 7

Wednesday, March 19, 1986

7:30 am Check out and depart from Rancho Grande Motel  
9:00 am Stop 1. Lyle's hectorite deposit  
11:00 am Lunch\* Jerome mining district and museum  
1:00 pm Stop 2. Camp Verde salt mine  
1:30 pm Depart for Tucson  
6:00 pm Arrive in Tucson. Stops at University of Arizona and  
Holiday Inn (Broadway)

\*Included in fees.

Drivers:

Field boots required. If possible, bring hard hat and safety glasses for mine tours.

FRONTIERS IN GEOLOGY  
6. Industrial Mineral Deposits  
(March 18-19)

March 11, 19

Rec#:	Name:	Ind Dep 6. \$ 90:
108	Steve Eady	1
71	Larry D. Estes	1
43	C. F. Sanchez	1
94	Peter D. Tillman	1
40	Eric Weiland	1
193	Pamela A.K. Wilkinson	1
	Ted Eyde	
	Grand Total	6

FIELD TRIP 6

INDUSTRIAL MINERAL DEPOSITS OF ARIZONA

March 18-19, 1986

Leader: Ted Eyde (GSA Resources, Inc.)

Coordinators: Pamela A. K. Wilkinson (Consultant)  
Erick F. Weiland (Consultant)

## FIELD TRIP TO SELECTED INDUSTRIAL MINERAL DEPOSITS OF ARIZONA

Ted Eyde<sup>1</sup>, Pamela A. K. Wilkinson<sup>2</sup>, and Erick F. Weiland<sup>3</sup>

MILEAGE      INTERVAL

TOTAL (mileage begins at intersection of Ina Road and Oracle Road - US 89, the mileage figures are estimates to the nearest whole mile).

- 0  
 Intersection of Oracle Road and Ina Road, proceed north on Oracle Road (US 89). The trip begins in the Tucson Basin. All domestic water for the city comes from wells drilled into the water bearing sands and gravels that fill the valley. The prominent ridge on the right is Pusch Ridge, part of the Santa Catalina Mountains that border the Tucson Basin on the north and northeast. These mountains are described as a metamorphic core complex. The prevailing idea is that metamorphic fabric was cataclastically derived during middle Tertiary extensional shearing. Extension was sufficiently prolonged to produce both ductile and brittle deformation. North of Tucson, US 89 passes between the Tortolita (Little Dove) Mountains on the west and the Catalina Mountains on the east. The prominent white scar in view in the Tortolita Mountains is a marble quarry which is developed in metamorphosed roof pendants of Permian Concha Limestone.
- 15  
 Junction of US 89 and State Highway 77, bear right onto SH 77.
- 26  
 The road cut on the right contains Oracle Granite. The road for the past few miles and the next few miles has been traversing a pediment developed on Oracle Granite.
- 29  
 The highway begins a descent into the San Pedro Valley. The headwaters of the San Pedro River are located in Mexico over 100 miles to the south. The highway passes one of the largest underground block-caving mines in the world (north side of highway). This is the San

-----

1) GSA Resources, P.O. Box 16509, Cortaro, AZ 85230  
 2) Consultant, 5632 East Kelso, Tucson, AZ 85712  
 3) Terra Technology, 412 N. Medford Dr., Tucson, AZ 85710

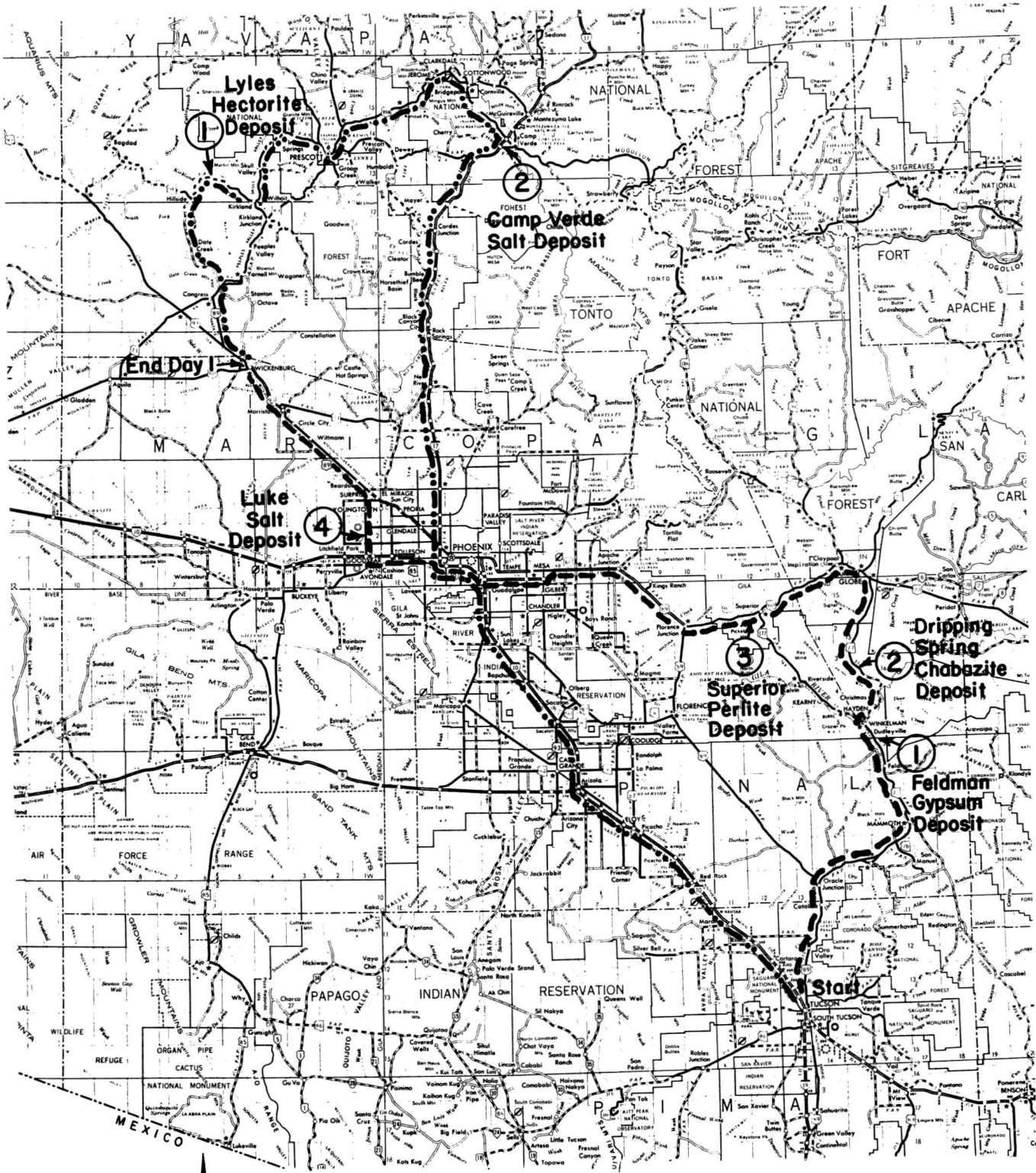
Manuel Division of the Magma Copper Company, which is owned by Newmont Mining Company. Cu is the primary metal produced but molybdenum, Au and Ag are also recovered. Since 1956 the mine produced over 4.5 billion lbs. of Cu. To the northeast across the valley the Galiuro Mountains, composed predominately of Cenozoic volcanic rocks, form the eastern margin of the San Pedro Valley.

- 8  
 37 Mammoth, AZ
- 9  
 46 Bridge over Aravaipa Creek. To the west across the San Pedro River are exposures of the younger Precambrian Apache Group and lower Paleozoic formations. Quarry operations are conducted by the San Manuel Division of the Magma Copper Co. Quartzite (high silica) is quarried and shipped by rail for use as a flux in their smelter at San Manuel.
- 1  
STOP 1  
 47 Entrance to The Superior Companies mining operations.

**FELDMAN GYPSUM DEPOSIT.** Most of the gypsum production in Arizona comes from a deposit on the east side of the San Pedro Valley about 6 miles south of Winkelman, Arizona. In 1984, the district produced about 250,000 tons of gypsum used in wall board, portland cement, and agricultural applications.

The gypsum-bearing zone occurs within a fine grained facies of the late Tertiary age Gila Conglomerate. Based on outcrops and drill hole information, the basin occupies at least 18 square miles principally along the east side of the San Pedro River. The lacustrine section dips about three degrees east. An exploration hole drilled to evaluate one of the deposits, intersected a continuous 300 feet thickness of interbedded clay and gypsum. Stratigraphic correlations between drill holes indicated that the section of interbedded clay and gypsum may be over 595 feet in thickness.

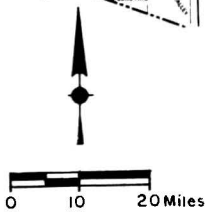
Aravaipa creek bisects the deposit. North of the creek 30 to 50 feet of massive gray gypsum with clay partings is being mined by National Gypsum Company and the Superior Companies. South of the creek the Pinal-Mammoth Gypsum Company mines a surficial deposit of gypsite which is from 7 to over 15 feet thick.



Legend

- ② Stop
- Day 1
- - - - Day 2

**Industrial Minerals  
Field Trip**





At both the National Gypsum Company and the Superior Companies operations the gypsum must be drilled and blasted. The broken gypsum is loaded and hauled to crushing plants where the minus 3/8 inch fraction is screened off. At both operations the final product contains 90 to 92% gypsum and less than 4% insolubles.

The Superior Companies ship gypsum to the Arizona Portland Cement Company at Rillito where it is used as a cement retarder. National Gypsum ships the Gypsum to their wall board plant in Phoenix. Crude gypsum used as a cement retarder sells for \$8 per ton F.O.B. the mine, whereas gypsum used in wall board sells for the equivalent of \$50-80 per ton.

The Pinal-Mammoth Gypsum Company is the major producer of agricultural gypsum in Arizona. Gypsite, containing 60 to 70% gypsum, is scraped from the surface and pushed into stockpiles with a dozer. The crude gypsite is hauled to a screening and bagging facility operated by the Company at Coolidge, Arizona. The screened gypsite is spread on croplands, golf courses, and parks to reduce soil alkalinity.

9  
56 Winkelman, Junction of State Highways 77 and 177, stay on SH 77, toward Globe.

1  
57 The stacks to the northwest are the 2 copper smelters at Hayden. The Kennecott Copper Corp. smelter is closed; the concentrator treats Cu ore mined at Ray, about 19 miles to the north. The Asarco smelter now treats Cu concentrates from Kennecott's concentrator and several Cu mines in southern AZ. The black material on the hill to the left is slag, the waste material from the smelting operations. The road follows the Gila River through the southern end of the Dripping Spring Mountains for the next several miles. Outcrops are carbonates of Mississippian and Pennsylvanian age. Dark-colored volcanic rocks of Cretaceous age directly overlie Paleozoic rocks.

9  
66 The Christmas Mine Division owned by Inspiration Mines Inc. is barely visible to the north and west.

3  
69 STOP 2

#### THE DRIPPING SPRINGS VALLEY CHABAZITE DEPOSIT.

A chabazite-bearing tuff horizon is exposed in a road cut on the east side of Arizona State Route 77 about 23 miles south of Globe, Arizona. Anaconda Minerals Company acquired the deposit in 1978 and since then has drilled over 100 holes to explore it.

The chabazite horizon is interbedded in a section composed of brown mud, sandstones, and limestones of probable Pliocene-Pleistocene age. The lacustrine beds are nearly flat-lying but dip gently toward the center of the Dripping Springs Valley. In the road cut, the

chabazite horizon consists of three lithologies: a lower thin-bedded to platy bed, a middle massive bed, and an upper thin-bedded to platy bed. Total thickness of the chabazite is nearly 2 feet. Sampling done in 1960 indicated that the middle massive bed is approximately 67% chabazite. Drilling by Anaconda Minerals Company revealed that the deposit consists of two chabazite-bearing horizons separated by what Anaconda geologists refer to as the red claystone bed which is about 5 feet thick.

The Anaconda drilling program showed that the lower zeolite horizon ranges from 0.50 to 1.74 feet thick and consists of three distinct lithologies that include a lower bed 0.15-0.87 feet thick consisting of zeolitically altered vitric ash and about 10% detrital matter. This bed is overlain by, and in sharp contact with, a bed 0.14-0.20 feet thick, consisting of a laminated, thin-bedded, zeolitically altered vitric ash containing a trace of detrital matter in addition to a trace of clay and calcite. Overlying this bed is a massive bed, 0.30-0.67 feet thick, of zeolitically altered vitric ash. This bed grades upward into the overlying red claystone.

The lower zeolite horizon grades from a clean unaltered vitric ash at the north end of the deposit to 90% chabazite at the south end of the deposit. The only other zeolite mineral present in the deposit is a trace of clinoptilolite. A system of paleochannels that flowed across the deposit has removed large portions of the deposit.

Chabazite is used in specialty adsorption applications such as sour natural gas treatment. The adsorption beds must be able to operate in a highly acidic environment to remove hydrogen sulfide, carbon dioxide, and water from the methane. Chabazite is also used in ion exchange applications such as treatment of low-level radioactive liquid wastes.

1  
70 Base of the grade that ascends the west slope of the Mescal Mountains, composed here of west dipping Paleozoic carbonates.

10  
80 Summit elevation 4983 feet. The Pinal Mountains are to the northwest (left) and the Mescal Mountains are to the southeast (right). The Pinal Mountains are composed largely of older Precambrian granite and Pinal Schist, whereas the Mescal Mountains are composed of the Younger Precambrian Apache Group sedimentary rocks and Paleozoic sedimentary rocks.

8  
88 Junction with US Highway 70. EPA Superfund trailer park at intersection. Jaquays asbestos mill in view to the right. Presently shut down. Turn left onto US 70 toward Globe.

1  
89 Globe, AZ Stay on US 70 through Globe and Miami, AZ. Over the period 1875-1981 the Globe-Miami Cu mining district has produced an estimated 11.5 billion lbs. of Cu, 20.5 million lbs. of Mo, 17 million oz. of Ag and 243

thousand oz. of Au, which is just over 17% of the total Cu production credited to AZ (total 66.6 billion lbs.) was taken from the area. Outcrops in the area are of Schultz Granite of Laramide age. Plutons of this age are closely associated with the primary Cu mineralization.

22

LUNCH STOP

- 111 Oak Flat picnic area in the Tonto National Forest. After lunch continue west on US 60. The route takes us through outcrops of the dacite member of the lower Miocene Apache Leap Formation. The upper parts of the cliffs east of Superior are also Apache Leap Formation. The road descends through a single well-developed cooling unit.

2

- 113 Road descends through well-exposed section of east-dipping Paleozoic carbonate rocks.

2

- 115 Town of Superior

SUPERIOR, ARIZONA. The Magma mine at Superior has produced about 1.8 billion pounds of Cu, 28 million ounces of Ag, and 535,000 ounces of Au from 18,000,000 tons of ore. Production has come from the Magma vein and replacement ore bodies in the Paleozoic limestones.

2

- 117 STOP 3.

Turn off to perlite processing plant and Apache Tear locality.

THE SUPERIOR PERLITE DEPOSIT. The first commercial production of perlite in the United States came from the deposits on the east side of Picket Post Mountain southwest of Superior, Arizona. In 1984 the district produced an estimated 50,000 tons of sized, unexpanded and crude perlite.

Perlite is mined from the perlite facies of the Tertiary age Arnett rhyolite. The perlite horizon mined ranges from 5 to over 100 feet thick. Guzman Construction Company produces crude crushed perlite for processing in Arizona. Harborlite and Silflo crush, screen and dry the perlite in processing facilities west of Superior. The sized perlite products are shipped out of state for expansion or "popping" into a light-weight cellular aggregate.

The expanded products, depending on the particle size and density, are used in formed construction products such as ceiling tile, roof insulation board, and pipe insulation; horticultural aggregate; loose fill insulation; and light weight aggregate. Several high value-added products are prepared by grinding and sizing the expanded perlite. These include filter aids and fillers. Attrition milling of the expanded products comminutes the perlite particles into a high aspect ratio, low bulk density cellular filler. Surface modified perlite is now used as a filler in engineering plastics.

In 1985 sized, unexpanded perlite sold for \$39 per ton F.O.B. the plant. The expanded products sold for \$165 per ton. The attrition

milled high aspect ratio products sold for over \$250 per ton. Perlite is an excellent example of how value can be added by additional processing.

15

- 132 Florence Junction: US 60 and US 89, continue west. The hills just north of the highway are eastward tilted blocks which are remnants of quartz latite ash flows. For the next 15 miles the highway parallels the trend of the Superstition Mountains, which are to the north and northeast. This range, the locality of the fabled Lost Dutchman Au Mine, is composed chiefly of volcanic rocks of Tertiary age: ash flows, air-fall and water-laid tuffs, mud flows and plugs that range in composition from basalt to rhyolite.

22

- 154 Junction - Temporary access to US 360, turn left

2

- 156 Junction: US 360 - Superstition Freeway, head west on freeway.

10

- 166 Junction of I-10 and Superstition Freeway - take I-10 west.

4

- 170 Cross the Salt River. Several sand and gravel operations can be seen in the river bed.

6

- 176 Exit - follow signs to I-10.

4

- 180 Turn right to I-10.

2

- 182 Turn left onto I-10, heading west.

11

- 193 Exit 129 - Dysert road - turn right, heading north.

4

- 197 The topographic rise here is the surface expression of the Luke Salt Body.

1

- 198 STOP 4.

Southwest Salt. After stop continue north on Dysert Road.

THE LUKE SALT DEPOSIT. The Luke Salt body which underlies Litchfield Park is exploited by solution mining. The salt deposit, which is of the late Miocene age, consists of at least a 4500 feet thickness of halite. Its complete lateral extent is not known. The halite was deposited as an evaporite facies in a local structural basin. There is evidence of some upward salt movement. The Luke Salt is composed of nearly pure halite which contains only traces of the blocking ions magnesium and calcium.

This is the only commercial salt operation in Arizona. Morton Salt Company which purchased Southwest Salt Company in 1985 uses solution mining to produce brine from the Luke Salt.

Solar ponds concentrate the brine to a saturated solution. In this environment the salt precipitates forming a layer of salt on the bottom of the ponds which is then removed by a salt harvesting machine. The crude salt is brine-washed to remove the insolubles and traces of magnesium and calcium and allowed to dry. It is shipped in bulk or bags to the users.

The salt, because of its low magnesium and calcium content, is a specialty product which in 1985 sold for \$40 per ton. It is used as a chemical raw material in the manufacture of chlorine swimming pool chemicals, as a chemical process aid in tertiary oil well recovery fluids, and domestic and industrial water softeners.

Higher purity chemical raw materials are being demanded by the consuming industries. Today, the cost of disposing of the waste brines from chlorine production often exceeds the cost of the raw materials. The amount of waste products generated can be reduced significantly by using only high-purity chemical raw materials which in turn reduces manufacturing and processing costs. At the Luke Salt deposit, three solution cavities are now leased to Cal-Gas for the storage of propane and butane. The waste brine and solids from the brine washing operation are reinjected into the salt through an injection well.

- 7  
205 Intersection. Grand Avenue. turn left, northwest.
- 5  
210 Volcanics in road cut on right have been in part zeolitized to the mineral clinoptilolite.
- 7  
217 Cross the Hassayampa River, enter the town of Wickenburg. End Day 1.

#### DAY 2.

- 0  
0 Intersection of US 89 and US 60-70. take US 89 north out of Wickenburg, toward Kingman.
- 5  
5 Junction US 89 and 93. bear right on US 89.
- 9  
14 Congress Mine at 12:00. The Congress Mining District has produced a minimum of 388,000 oz. of Au from relatively high-grade ore shoots in hypogene auriferous quartz veins. The district ranks second in primary Au production in Arizona. Essentially all of the district's Au production has come from two vein systems: The Congress and Niagara veins. The original claims were located in 1887 and most of the Au production occurred between 1894 and 1911. The property was owned by Echo Bay Exploration, Inc. in 1985.
- 1  
15 Junction US 89 and SH 71. bear right on US 89 to Prescott.

- 2  
17 Turn left on graded-gravel road to Hillside - Bagdad.
- 1  
18 Bear right at fork. The Weaver Mountains are to the northeast (right) and the Date Creek Mountains are to the southwest (left).
- 18  
36 Town of Hillside. Rail loading facilities for the Bagdad Copper Mine, which is located approximately 15 miles northwest of here.
- 18  
54 Bear right toward Prescott.
- 4  
58 Lyles Hectorite Deposit at 2:00 white area on hillside.
- 1  
59 Kirkland Peak at 12:00.
- 1  
60 STOP 1  
LYLES CLAY DEPOSIT

THE LYLES HECTORITE DEPOSIT. The Lyles hectorite deposit is one of only three deposits producing hectorite in the United States. The others are at Hector, California operated by N. L. Chemicals, and Imvite, Nevada operated by IMV (Industrial Minerals Ventures), a subsidiary of Gulf Resources and Chemical Corporation. Sometime during the mid 1950's, Joseph Lyles of Yarnell discovered that the clay from the deposit contained detectable amounts of lithium. He brought the property to the attention of E. T. Turley of Phoenix, Arizona, who explored the deposit with pits and auger holes. Later Mr. Turley mined hectorite for use as a sealant for irrigation ditches and stock ponds.

The deposit was acquired in the early 1960's by the James Stewart Company of Phoenix who were interested in the deposit as a source of lithium. In 1982, GSA Resources acquired the deposit and began a drilling program to evaluate the hectorite deposit. Bulk sampling and pilot plant testing were completed in 1985. In 1986, the first shipment was made from the deposit to a specialty clay producer.

The deposit is interbedded within a section of lacustrine clays at least 70 feet thick which is overlain by a 1 to 2 feet thick bed of vitric tuff zeolitically altered to phillipsite. Another bed of vitric tuff zeolitically altered to clinoptilolite occurs below the hectorite bed. The zeolite beds are excellent marker horizons.

The hectorite bed is 8 to 35 feet thick. It is both overlain and underlain by high alumina smectites. The hectorite, when freshly mined, ranges from a translucent waxy white to a light yellowish white color. Much of the hectorite actually resembles white candle wax.

The hectorite horizon contains large concretions of chalcedony and dolomite. It appears that the hectorite in fact is a hydrothermal clay deposit. A travertine mass crops out in the valley along the east side of the deposit. The relationship between travertine masses and high magnesium smectite has been noted at both the Imvite and Hector deposits as well as at other deposits of saponite and high magnesium smectite.

The deposit appears to have formed when thermal spring waters rich in magnesium were introduced into the normal high alumina smectite in the lacustrine beds. The existence of the thermal springs is strongly suggested by the travertine deposits which are usually linear, vein-like structures. The hectorite bed actually may be the result of magnesium metasomatism of a high alumina smectite clay horizon. The silica and dolomite concretions may indicate the migration of thermal waters through the hectorite bed.

Hectorite is used as a thickener and viscosifier in many products such as paints, saltwater drilling muds, and liquid shampoos. Some hectorite products are organoclad with quaternary compounds which make the hectorite organophilic. Organoclad hectorite is used in thickeners and viscosifiers in oil based paints, greases, oils and oil based drilling muds. Organoclad clay products, such as the Bentones, and Benagels manufactured by N. L. Chemicals, sell for over \$1.00 per pound.

After stop return to highway, and continue northeast.

10  
70 Quarry - produced pumiceous tuffs for building stone, used in the post office and warehouse. Turn left across the tracks. City of Kirkland.

2  
72 Pahoco Mines Ltd. A crushing and screening plant, now dismantled processed pumiceous tuff for use in animal absorbents.

4  
76 Skull Valley, AZ

17  
93 Prescott, AZ

8  
101 Junction, US 89-A, to Jerome, turn right, stay on US 89-A.

6  
107 Prescott Valley. Route up Mingus Mountain traverses Precambrian Spud Mountain Volcanics and Grapevine Gulch Formation, which are separated by the Shylock fault. Paleozoic formations are: Tapeats Ss(C), Martin Formation (D) and Redwall Ls(M). These are overlain by basalts of the Hickey Formation which cap Mingus Mountain.

4  
111 San Francisco Peaks may be visible at 12:00, if the weather is clear.

115 Cross the Warrior Fault which juxtaposes Paleozoic Martin Formation and Precambrian Grapevine Gulch. Workings on left of road are of the Jerome Grande Mine.

Workings to right after the two switchbacks are the Verde Central. Outcrops are in the Precambrian Cleopatra Rhyolite. This unit is also the host for the United Verde orebody, the open pit mine located over the hill to the north.

2  
117 Outskirts of Jerome. Cross the Verde Fault. Precambrian on the west and Hickey Volcanics on the east. Subsidence along this fault has caused many of the houses in the town to crumble and slide down the hill.

Turn left to State Historical Park -

LUNCH STOP - and tour the museum.

JEROME MINING DISTRICT. Mining in the Jerome district began in 1870. The metals produced during this period were Au and Ag. Copper mining began at Jerome in 1883. W.A. Clark, who also owned many of the Cu mines at Butte, Montana, obtained control of the United Verde mine in 1888 and began the period of highly successful mining operations. The smelter town of Clarkdale was named after him.

The United Verde Extension ore body was discovered in 1914. The United Verde and United Verde Extension mines were the sources of 99% of the production from the Jerome district. The United Verde Extension mine closed in 1938 and the United Verde mine in 1953. The district produced 1,890,000 ounces of Au, 65,600,000 ounces of Ag, 1,868,000 tons of Cu, 37,725 tons of Pb, and 127,000 tons of Zn. It is estimated that a reserve of 750,000 tons of Zn occurs in the estimated 12,000,000 tons of massive sulfides still remaining in the United Verde mine.

After lunch return to US 89-A and continue northeast.

4  
121 Portland cement plant at 9:00, owned and operated by Gifford Hill. Source of the limestone is the Tertiary age Verde Formation.

1  
122 Junction Clarkdale/Cottonwood bypass, turn right to Sedona /Flagstaff.

3  
125 Town of Cottonwood.

1  
126 Junction, turn right to Sedona /Flagstaff.

5  
126. Junction US 89-A and 279, bear right toward Phoenix on 279.

12  
138 Junction I-17, continue on 279 across I-17.

2  
140 Town of Camp Verde

1  
141 Salt Mine Road, turn right

1  
142 STOP 2  
Camp Verde Salt Mine

THE CAMP VERDE SODIUM SULFATE DEPOSIT. The Camp Verde Sodium Sulfate Deposit has been known for 2000 years. In fact, it may be the oldest mine in the State of Arizona. Evidence of pre-Columbian activity, which included artifacts and the mummified remains of a miner, were discovered when the mine was operated during the 1920's. The Spanish explorers Antonio de Espejo in 1583 and Marcos Farfan de los Godos in 1598 are both believed to have visited the mine.

The evaporite sequence which consists of halite, mirabilite and glauberite is as much as 46 feet thick at the Camp Verde Salt Mine. The evaporites grade into gypsum and halite in the deeper part of the basin southeast of Camp Verde. The Superior Companies mine gypsum from a deposit in the gypsiferous facies and ship it to Gifford Hill Cement plant in Clarkdale, Arizona. Aragonite crystals and, more rarely, needle-like pseudomorphs of glauberite can be found on the high wall along the west side of the old pit. Beautiful acicular crystals of mirabilite can be found in the drainage ditches.

The Verde Formation, which hosts the evaporites, consists of at least 1600 feet of sediments. It is believed the basin formed during the Oligocene time possibly as a result of movement along the Verde Fault zone. During Miocene time, the drainage through the south end of the valley was blocked by volcanics resulting in a closed basin in which a saline-alkaline lake formed. When the Verde River breached the volcanics during the Pleistocene, the resultant erosion exposed the evaporites.

Western Chemical Company began surface mining operations during the 1920's to exploit what was believed to be the largest deposit of sodium sulfate in the world. In the early 1930's, Arizona Chemical Corporation, a joint venture between American Cynamid and International Paper Company, acquired Western Chemical Company. Underground mining was started using room and pillar mining methods.

The crude sodium sulphate-halite mined underground was transported to the processing facilities on a conveyor belt. About 100 tons of salt cake, anhydrous sodium sulfate, was produced per day making it the largest producer in the United States. The mine closed in 1933 when low priced high purity sodium sulfate from Germany began entering the United States. Some exploration drilling was done on the sodium sulfate deposits in the Camp Verde area by Stauffer Chemical Company in the 1960's but the mining operation was not reopened.

Sodium sulfate is used principally in the manufacture of kraft paper pulp which is also known as sulfate pulp. About 88 pounds of sodium sulfate is used to produce a ton of

kraft paper pulp. Another major and fast growing use of sodium sulfate is in washing detergents where it is a noncorrosive, neutral and cheap filler with mild detergent properties. The other principal use is in flat glass production. The major markets for sodium sulfate in the United States are:

Kraft paper pulp	55%
Detergents	35%
Glass	5%
Other uses	5%

Sodium sulfate sold for \$90 to 96 per ton in carload lots F.O.B. the works in 1984.

After stop retrace route back to 1-17, head south to Tucson.

Arizona Industrial Minerals;  
A Growing Industry in Transition  
Ted H. Eyde and Jan C. Wilt, 1985

Abstract

Industrial minerals have been mined in Arizona since the dawn of civilization. The applications of these remarkable minerals have become increasingly sophisticated until today industrial minerals are displacing metals from many of their traditional uses. Production of industrial minerals in Arizona has increased steadily because of increasing population and living standards. In 1984, 205 operations produced \$245 million worth of industrial minerals. In fact, the tonnage and value of aggregate production is exceeded only by copper. In the past 25 years both the kind and quantity of industrial minerals has increased rapidly. The state is an important producer of aggregate, cement, lime and gypsum which are used principally in the construction industry. It also is a major producer of specialty industrial minerals such as bentonite, high purity salt, perlite, and zeolite. Deposits of hectorite, diopside, and celestite are being developed. Industrial minerals production should continue to increase with an expanding population base unless the resources become unavailable because of increases in the acreage of public lands in

wilderness and urban areas. Imposition of a single fiber mineral standard for airborne particulates could also restrict development of deposits containing fibrous minerals.

### Introduction

The production of industrial minerals and rocks continue to show dynamic growth. According to preliminary production figures from the U. S. Bureau of Mines, the value of nonmetallic production in the United States in 1984 was nearly \$16.7 billion. This is nearly three times greater than the \$6 billion value of metal production. Thus, it seems incredulous that many geological publications still relegate industrial minerals to a brief section at the end of a report which lists a few localities accompanied by brief geological descriptions. In fact many articles are reminiscent of the elementary description of rocks and minerals found in many beginning geological textbooks. This suggests that even now many geologists do not really understand the reasons why some industrial mineral deposits are exploited whereas others are not.

In addition, the geological literature often lags behind the actual production of marketable products from an industrial minerals deposit. Perlite, for example, is an industrial mineral which did not appear in publications or on maps showing the

location of industrial minerals deposits and occurrences until shortly before commercial production began near Superior, Arizona in 1946 (Wilson 1945). In fact, the first edition of Industrial Minerals and Rocks by Raymond Ladoo published in 1925 does not mention perlite. The second edition published in 1951 includes perlite and notes that the most productive deposits in the United States are near Superior, Arizona (Ladoo and Meyers 1951).

Even experienced field geologists frequently do not recognize potentially valuable industrial mineral deposits, nor are they familiar with the analytical techniques required to identify and evaluate them. Therefore, the industrial mineral resources are frequently overlooked when the mineral resources of lands being considered for inclusion in the wilderness system are being inventoried. This means that important unrecognized industrial minerals resources that are needed for products being developed through recent advances in materials science will likely be lost to wilderness areas and to urbanization.

Industrial minerals include all those earth materials used by man except metallic ores, mineral fuels, water, and gems (Harben and Bates, 1984). The term nonmetallics is not entirely synonymous with industrial minerals. Many so-called nonmetallics are in fact metallic minerals. For example, the oxidized manganese minerals which have been mined in Arizona are considered to be industrial minerals when used in water treatment systems or dry



cell batteries, and are considered to be metallics when used in steel and ferro alloys. Thus, the end use of the mineral rather than its composition often determines whether the specific mineral is considered a metallic or nonmetallic mineral, or in some cases both. In fact, mineralogy rather than composition is often the principal determinant of the end use application of industrial minerals. Whereas, in the case of metallic ores and minerals, the grade, which is the recoverable content of such elements as gold, silver, copper or lead, assuming adequate reserves are developed, determines whether a deposit is exploitable.

Highly sophisticated processing is usually required to convert a crude, mine-run mineral or rock into a marketable, value-added, specialty industrial mineral product. For example, the processing required to convert the crude bentonites from the Cheto deposit in northern Arizona into marketable products such acid activated bleaching clays, desiccants, catalysts, and organoclad clays used as thixotropic agents and suspension stabilizers is complex. In fact, producing these products requires processing technologies far more advanced than those generally in use at most of Arizona's metallic milling and smelting complexes. Actually, the rapid growth of the industrial minerals industry has resulted from the quantum leaps in materials science which

has produced such products as fiber optics, fiber reinforced resin systems also known as composites, molecular sieves, and pillared clays.

Industrial minerals were first utilized at the dawn of civilization as tools, weapons, cooking vessels, and materials used in the construction of shelters for Arizona's pre-Columbian Indian civilizations. Ironically, many of these same industrial minerals are now displacing the metals introduced by the Spanish settlers whose metal swords and guns defeated these ancient primitive civilizations. In the past, advances in metallurgy resulted in the replacement of the stone tools and implements by those fabricated from bronze, iron, and then steel. Now, materials technology has for example developed fiber-reinforced resin systems known as composites, which are rapidly displacing metals in many traditional applications such as aircraft wings and fuselages, automobile and truck bodies, and construction materials.

Some of the more recent developments in mineral processing include delamination, which disaggregates the individual clay crystals into micron-range cleavage fragments, high intensity wet magnetic separation to remove magnetic minerals, ultraflotation to separate fine-grained gangue minerals, and attrition milling to enhance the aspect ratio of fibrous minerals used as fillers in high strength engineering plastics. Other recent advances

include the treatment or modification of minerals to alter their surface properties.

Clays can be organoclad, by treating them with an organic compound to render them compatible with oil, brine, or fresh water based systems. The viscosity of all these systems are greatly improved by organocladding. Mineral fillers used in plastic resin systems are surface modified with coupling agents such as the silanes to increase surface bonding, a property which is important in the formulation of engineering plastics.

Continuing advances in mineral technology will result in expanding markets for high purity industrial mineral products. This will result in a better understanding of both the mineralogy and ultimately the geological setting of many industrial minerals resources.

The geology and mineralogy of the Arizona industrial mineral deposits productive during the past 25 years are described along with the end use product applications. Unique characteristics of the deposits are discussed. These may include many seemingly unrelated factors such as the mineralogy, chemical composition, geological setting, or location which either together or separately resulted in the mineral products from the deposit being marketable.

## Historical Perspective

Industrial minerals have been produced and used in Arizona and the southwest for thousands of years. The use of industrial minerals predated the arrival of the Spanish explorers and may even predate modern man. At the Calico Early Man Site in California, the lowest artifact bearing deposits at the site consists of an assemblage of stone tools that are at least 200,000 years old (Budinger, 1983).

Montezuma's Castle near Camp Verde, the Casa Grande Ruins, and other Indian ruins which still endure in Arizona demonstrate the prehistoric use of stone and adobe in construction. These ruins also contain artifacts which indicate that the inhabitants made flint, chert, and chalcedony into arrow heads, axes, skinning tools and knives. The Indians also developed tools for drilling and shaping turquoise and highly colored stones into beads and jewelry. They also shaped and colored clays and fired them into nonporous, durable, colored ceramic pots.

In addition, the Indians were aware of the need for salt in human and animal nutrition, and in food preservation. Evidence of pre-Columbian salt mining activity was discovered at the Camp Verde salt mine in central Arizona. The artifacts and mummified remains of a miner found there prove this was one of the oldest underground mines in the United States (Thompson, 1983). The

early Spanish explorers Antonio Espejo and Marcos Farfan de los Godos saw salt being mined at the Camp Verde deposit as early as 1583 (Bartlett, 1942).

The Spanish settlers brought with them skills in building with brick and mortar which included the construction of arches, a skill not possessed by the Indians. The construction of arches required the ability to make dimensionally uniform bricks as well as lime mortar from clean sand and calcined limestone. The Spanish settlers utilized deposits of dimension stone, marble, limestone, sand and gravel, gypsum and clay as sources of local building materials.

They also brought with them the technology for manufacturing glass and glazes. Certainly, the raw materials required in the manufacture of glass and glazes, such as silica sand, feldspar, sodium compounds, and limestone were available in Arizona. Consequently, stained glass windows, glasses, glazed table ware, and colored ceramic tile soon became common place in the Spanish settlements in Arizona. At first these products were imported from Spain; later, local artisans manufactured them in Arizona.

American settlers migrating into Arizona during the 19th century brought with them a demand for more and better construction materials, sanitary ware, and chemical products. To satisfy

these demands, sand and gravel, dimension stone, gypsum, salines, limestone, and clay deposits were developed.

During the twentieth century new markets for specialty industrial minerals began developing. Deposits of chrysotile, barite, bentonite, perlite, and zeolites were brought into production. Virtually all of the production from these deposits was and still is shipped out of the state for processing into high value-added, industrial mineral products. These industrial mineral products are returned to Arizona in electronic equipment, household appliances, automobiles, and many other consumer products.

Future development of the industrial mineral resources of Arizona will continue to be closely linked both to the rapid population growth and to the rising standard of living. As the population of Arizona increases, more value-added processing of industrial minerals will be done within the state to supply mineral products for the rapidly expanding consumer markets.

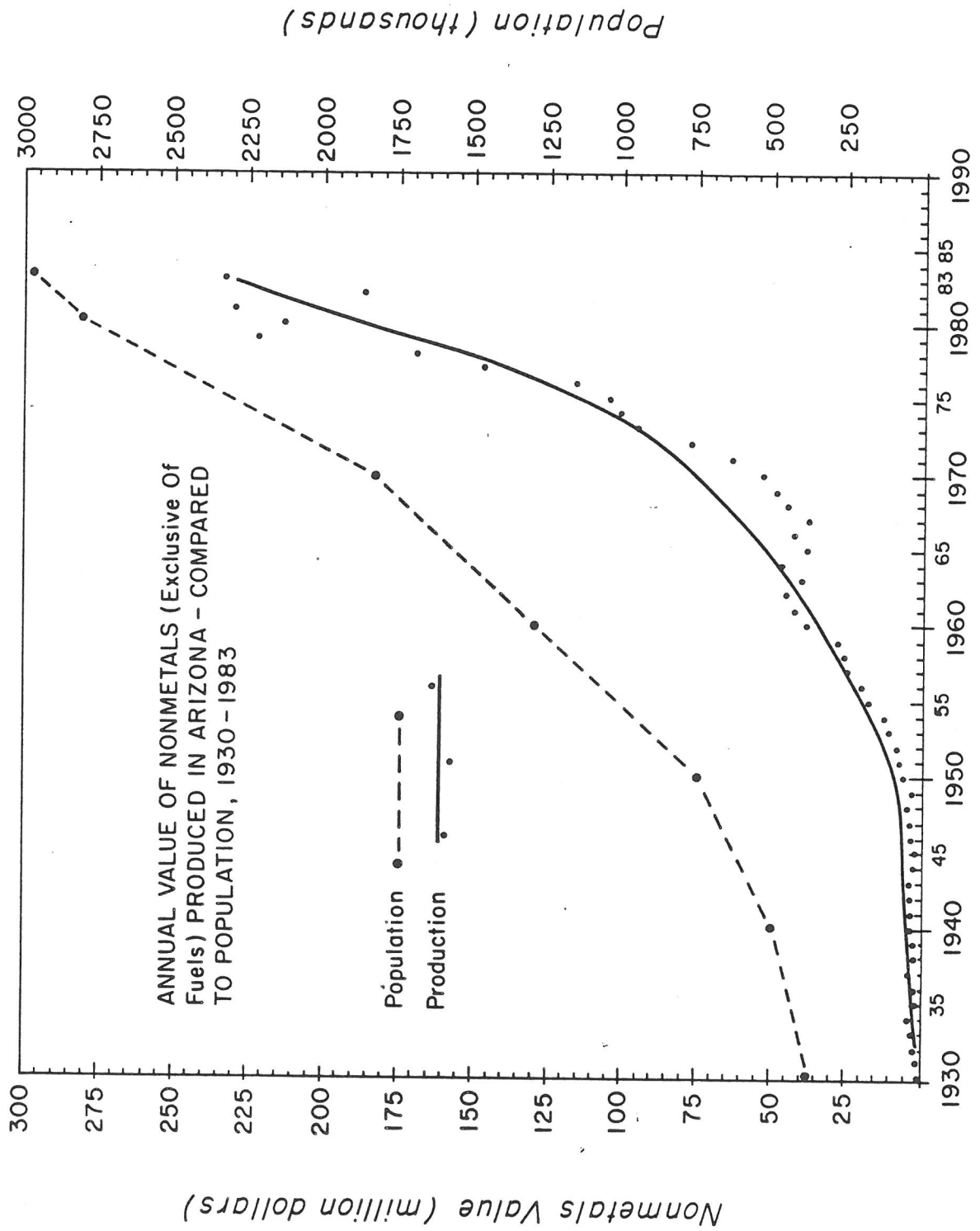
### Production

The Arizona State Mine Inspectors Annual Report for 1984 lists 251 locations including those operated by the Arizona Department of Transportation where industrial minerals were mined or processed. In 1984 the Arizona Department of Mines and Mineral Resources Directory of Active Mines in Arizona listed 205

industrial mineral producers which includes 168 producers of gravel and crushed stone and 43 producers of other industrial minerals. Six of these operations produced silica flux for copper smelting. These statistics reveal that today the small miners produce industrial minerals and not precious or base metals.

According to The U.S. Bureau of Mines Mineral Industry Surveys, in 1984 the value of industrial minerals produced in Arizona reached \$245 million; this is 17.5% of the \$1.4 billion value of nonfuel minerals production in the state. Specifically, both the value and tonnage of aggregate produced was exceeded only by that of copper. Historically the value of industrial minerals production has kept pace with the population growth in the state (Figure 1). If this growth continues, industrial minerals production could surpass metals production both in tonnage and value by the end of the twentieth century.

Though Arizona industrial mineral production can be calculated on a per capita basis, the result does not represent the increase in the consumption of industrial minerals outside of the construction industry. Based on the U.S. Bureau of Mines Annual Mineral Industry Surveys and unpublished production data supplied by the producers, over 98% of the tonnage of industrial minerals produced in Arizona is consumed by the construction industry.





And, most of the remaining 2% of production are either crude or semi processed mineral products shipped out of the state for processing into marketable products.

The data compiled by Austin (1983) provides a more accurate appraisal of the increase in both the total and per capita production of selected industrial minerals in the United States between 1931 and 1981. Overall, the increase in the domestic production of construction materials such as sand and gravel +396%, cement +209% lagged far behind the minerals used in specialty applications such as mica +1643% and bromine +4800%. These comparisons are also reflected in the per capita production of these same minerals (Figures 2 and 3).

Both tables present only the United States production data. However, if data on the per capita consumption of industrial minerals were available it would also include imported industrial minerals. Imports now supply all of the celestite, most of the fluorite and asbestos and much of the gypsum as well as other industrial minerals consumed in the United States. Therefore, the per capita consumption of industrial minerals would be significantly higher than indicated in Figure 3. It is reasonable to believe that the per capita consumption of industrial minerals in Arizona is comparable with the rest of the United States. And further, that with the introduction of plastic

DOMESTIC PRODUCTION OF 17 COMMODITIES IN 1931, 1932, AND 1981 WITH PERCENT  
CHANGE IN PRODUCTION FROM 1931 TO 1932 AND 1931 TO 1981 (Austin, 1983)

Commodity	1931	1932	% Change from 1931	1981	% Change from 1931
<u>Industrial</u>					
Asbestos	2.9	3.2	+ 10 %	81.0	+ 2693 %
Barite	191	121	- 37 %	2,177	+ 1040 %
Boron	162	165	+ 2 %	680	+ 320 %
Bromine	4.0	2.6	- 35 %	196	+ 4800 %
Cement	21.4 Mt	13.0 Mt	- 39 %	66.2 Mt	+ 209 %
Feldspar	149	106	- 29 %	626	+ 320 %
Fluorspar	48.5	22.9	- 53 %	104	+ 114 %
Lime	2.5 Mt	1.7 Mt	- 32 %	17.5 Mt	+ 600 %
Mica	6.4	6.7	+ 5 %	111	+ 1634 %
Sodium Carbonate	71.2	50.2	- 29 %	7,575	+ 10,539 %
Sodium Sulfate (nat.)	29.5	29.2	- 1 %	540	+ 1731 %
Sulfur	2.16 Mt	0.90 Mt	- 58 %	12.4 Mt	+ 474 %
<u>Agricultural</u>					
Phosphate Rock	2.62 Mt	1.74 Mt	- 34 %	57 Mt	+ 2076 %
Potash	121	129	+ 7 %	2,150	+ 1677 %
<u>Other</u>					
Gypsum	2.3 Mt	1.2 Mt	- 48 %	10.9 Mt	+ 374 %
Salt	6.7 Mt	5.8 Mt	- 13 %	35.8 Mt	+ 434 %
Sand and Gravel	139.0 Mt	80.7 Mt	- 42 %	689 Mt	+ 396 %

Domestic production figures from the U.S. Bureau of Mines (1933a; 1933b) and Lefond (1982).  
All tonnages in kilo tonnes unless otherwise indicated.

**PER CAPITA DOMESTIC PRODUCTION OF SELECTED INDUSTRIAL  
MINERALS IN 1931 AND 1981 (Austin, 1983)**

	1931	1981	% Change
Asbestos	0.05 lbs.	0.8 lbs.	+1500 %
Barite	3.4	21.4	+529 %
Boron	2.9	6.7	+131 %
Bromine	0.07	1.9	2614 %
Cement	378	651	+72 %
Feldspar	2.6	6.16	+137 %
Fluorspar	0.86	1.0	+16 %
Gypsum	41	107	+161 %
Lime	44	172	+291 %
Mica	0.11	1.1	+900 %
Na Carbonate	1.3	74.5	+5631 %
Na Sulfate	0.5	5.3	+960 %
Phosphate	46.2	560	+1112 %
Potash	2.14	21.2	+891 %
Salt	118.5	352	+197 %
Sand and Gravel	2,455	6,779	+176 %
Sulfur	38	122	+121 %

Domestic production figures from the U.S. Bureau of Mines (1933a; 1933b) and Lefond (1982). Population figures for 1932 (124,840,000) and 1980 (224,066,000) were used in the calculations.

composites, fiber optics, and ceramics that the consumption and the production of industrial minerals will continue to increase.

### Classification

Because of the wide diversity in chemical and physical properties, origin, and end use applications of industrial minerals, several schemes have been devised to classify industrial minerals. Bates (1960) used both geology and value to establish a two-fold subdivision of nonmetallics. Those which had a high place value were classified as industrial rocks whereas those with a high unit value were classified as industrial minerals .

The Bates classification conformed with the geological origin of the deposits. It did not, however, foresee that future advances in mineral processing technology would move many commodities classified as high place-value industrial rocks to the high unit-value industrial minerals. Clay, perlite, marble, and salt, with value-added processing become organoclad clays, surface modified and micronized grades of calcium carbonate, specialty filler and filtration grades of perlite and high purity salt. The selling prices of these mineral commodities range from \$40 per ton for high purity salt to over \$2000 per ton for organoclad clays.

Bates reissued his textbook in 1969 with an expanded list of references (Bates, 1969) and in 1984 he coauthored with Peter Harben The Geology of the Nonmetallics (Harben and Bates, 1984).

The authors recognized that recent developments in the industrial minerals industry revealed:

1. More rigid specifications are required by the consuming industries.
2. More elaborate processing techniques are available.
3. More sophisticated applications and new end uses have developed.

Harben and Bates (1984) revised the classification originally proposed by Bates. Though the revised classification (Figure 4) remains geological, unlike the earlier classification (Bates, 1960) it does not attempt to categorize low unit value nonmetallics as industrial rocks and the high unit value nonmetallics as industrial minerals. Instead, this classification recognizes the changing role of industrial minerals in a developing world economy and allows for the continuing shift away from low unit value nonmetallic commodities to high value-added processed industrial minerals, which are in reality specialty chemical products.

# CLASSIFICATION OF NONMETALLICS

( Harben and Bates, 1984 )

IGNEOUS	SEDIMENTARY	SURFICIALLY ALTERED	METAMORPHIC
Intrusive	Clastic	Vermiculite	Marble
Olivine	Sand and gravel	Manganese minerals	Slate
Chromine	Sandstone	Bauxite	Asbestos
Nepheline syenite	Clays	Iron oxide	Talc
Granite	Titanium and zirconium minerals	Tripoli and novaculite	Magnesite and magnesite
Pegmatitic and hydrothermal	Rare - earth minerals	Zeolites	Graphite
Mica	Diamonds		Corundum and emery
Quartz crystal	Biogenetic		Garnet
Lithium minerals	Limestone and dolomite		Wollastonite
Beryllium minerals	Diatomite		Sillimanite minerals
Fluorspar	Phosphate rock		Pyrophyllite
Feldspar	Sulfur		
Extrusive	Chemical		
Basalt and related rocks	Barite	Potassium minerals	
Pumice and scoria	Salt	Borates	
Perlite	Sodium carbonate	Celestite	
	Sodium sulfate	Nitrates	
	Nahcolite and dawsonite	Bromine	
	Gypsum	Iodine	

Geological classifications can assist in the discovery of deposits. Grouping industrial minerals according to a geological classification which reflects their genesis is unquestionably useful for mineral exploration. The genesis of specific industrial mineral deposits when combined with the age of the deposit provides an excellent regional exploration tool. For example, the most productive chrysotile asbestos deposits occur in Precambrian age dolomites or ultramafic complexes. Therefore in Arizona, an exploration program for chrysotile should be confined to mountain belts in which the Mescal Limestone and diabase in the Precambrian Apache Group are exposed. This is of course where all of the known chrysotile deposits occur.

Discovering an industrial minerals deposit does not guarantee a profitable industrial minerals operation. Therefore, it is equally important to recognize the potential end use applications of industrial minerals. Charles H. Kline published a classification for industrial minerals which is based on their end use applications (Klein, 1970). The classification groups industrial minerals into the two categories of chemical minerals and physical minerals.

#### 1. CHEMICAL MINERALS

- Chemical raw materials
- Fertilizer raw materials
- Chemical process aids
- Ceramic raw materials
- Metallurgical fluxes

#### 2. PHYSICAL MINERALS

- Structural minerals
- Filler and extender pigments
- Process aids
- Absorbents, carriers, and parting agents

Some industrial minerals are both chemical and physical minerals. Barite is a chemical raw material when it is converted to barium carbonate for use in glass radiation shields in television sets. It is a physical mineral when used as a process aid to add weight to drilling fluids or as a pigment extender in paints. Silica is a chemical mineral when used as a metallurgical flux and is a physical mineral when used as a pigment extender in reflective paints. This grouping by end use application is often based on the mineralogy of the specific industrial mineral.

Grouping of industrial minerals by end use applications may seem superfluous. However, just 30 years ago industrial minerals such as perlite and wollastonite which were only mineral curiosities, are now used as fillers and process aids because the shape, size and nonreactivity of the mineral particles which make them suitable for filler and filtration applications were recognized and then enhanced by sophisticated processing techniques. Some industrial minerals are site specific because of unique physical or chemical characteristics which occur only at a specific deposit.

The zeolite mineral chabazite from the Bowie deposit for example is used as a specialty adsorbent. This is because its higher silica content increases its acid resistance and also because its microcrystallinity results in a large surface area which promotes





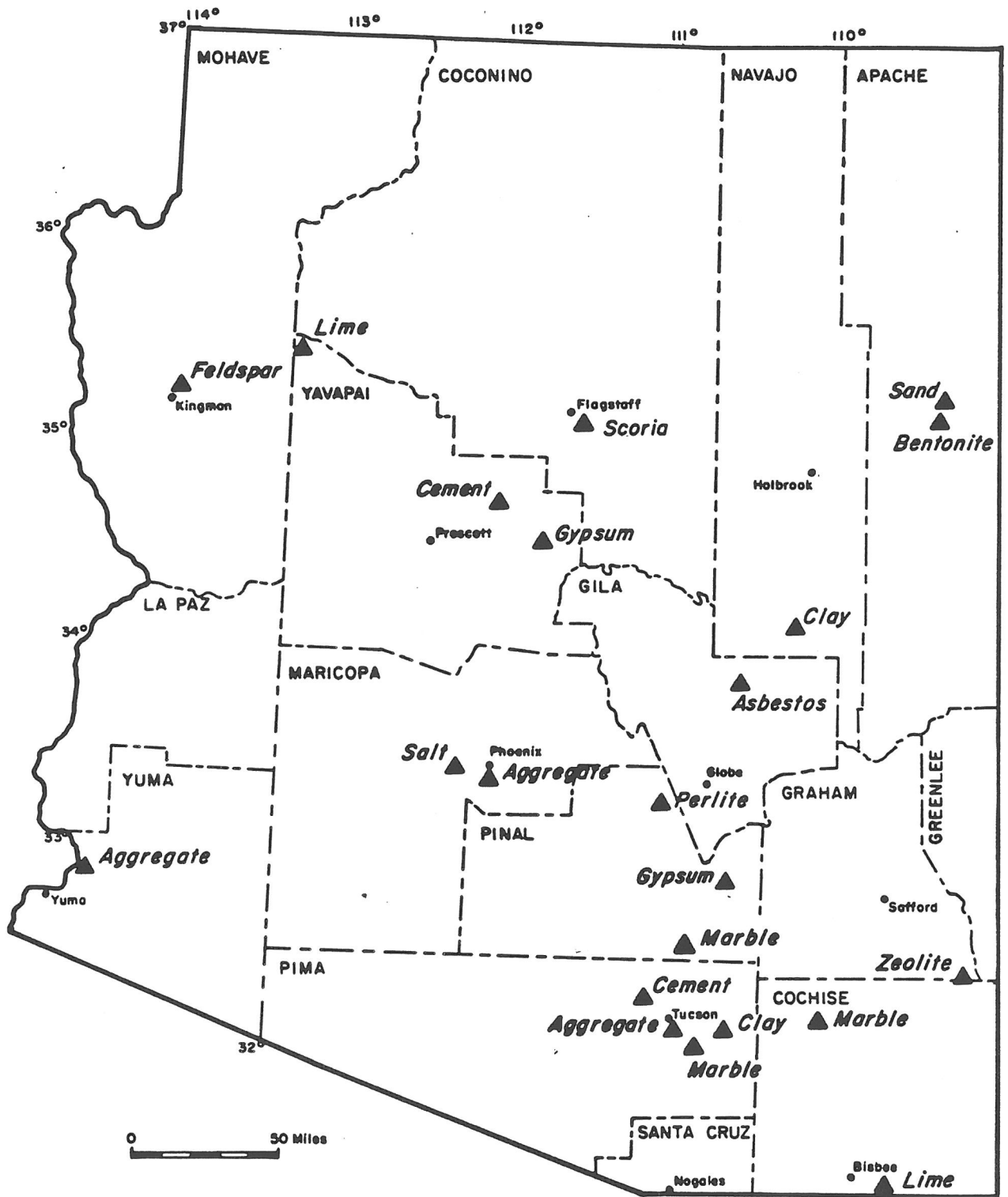
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rapid adsorption and desorption of liquids and gases. (Figure 5). It is because of these properties that chabazite from the Bowie deposit is a physical and chemical process aid marketed by the Linde Division of Union Carbide Corporation as its specialty adsorbent AW-500 molecular sieve. It is used in pressure-swing-adsorption installations which treat sour natural gas to remove water, carbon dioxide, and hydrogen sulfide from methane.

#### Productive Arizona Industrial Minerals Deposits

During the 25 year period between 1960 and 1985 at least 14 industrial minerals were produced from deposits in Arizona. (Figure 6). Production of two of these commodities ceased during this period. The discontinued operations include the feldspar mine and grinding plant at Kingman and the chrysotile asbestos mines and processing plants near Globe. However, during the same 25 year period, production began at high alumina clay deposits at Pantano and near Clay Springs, a hydrofrac sand deposit near Houck, a zeolite deposit near Bowie, marble deposits near Tucson, and a salt deposit near Litchfield Park.

The feldspar mine and plant at Kingman closed because the reserves of feldspar and coproduct quartz exploitable by surface mining were approaching depletion. The grinding plant in Kingman, which for several years after the mine closure operated on stockpiled quartz, was closed in part because the plant would



MAJOR ARIZONA INDUSTRIAL MINERALS DEPOSITS PRODUCTIVE  
BETWEEN 1960 AND 1985

require substantial modification to meet standards for free silica in airborne particulates. Closure of the chrysotile asbestos operations in Globe was forced because of an assumed risk to persons not employed by the industry who resided at the nearby Mountain View Mobile Home Park (Peirce and Garcia, 1983).

Industrial minerals mining and processing operations face two threats to their continued operation. The first threat is that urbanization, recreational uses, and scenic values are usually accorded a higher priority than the development and production of industrial minerals resources. Thus, industrial mineral deposits become locked up in wilderness areas or when urbanized are designated public nuisances and forced to close.

The second, and even more serious threat is the policy initiated by OSHA to place all the estimated 152 minerals that have fibrous varieties under a single fiber standard based only on the size and shape of the fiber. Mineralogy, chemical composition, and surface reactivity of the fibrous minerals are not considered. Thus, fibrous minerals such as, tremolite, wollastonite, and chrysotile would all be classified as asbestiform and the airborne particulates from these minerals would be subject to stringent regulations. Imposition of a single fiber standard would be tantamount to legislating against the crust of the earth and would result in the permanent closure of many mines, quarries and gravel pits (Thompson, 1984). This situation underscores the

importance of quantitative mineralogy in monitoring not only processing plant feed and product quality, but also the liquid and solid waste products and particulate emissions.

### Aggregate

Aggregate is the most important industrial mineral produced in Arizona which is exceeded only by copper in terms of tonnage and value. Most of the aggregate produced in Arizona is sand and gravel. It is classified by origin as a clastic sedimentary rock and by end use whether sand and gravel or crushed stone, as a physical mineral. When used in concrete or asphalt, aggregate is a structural mineral that increases the strength of the final product. Without the addition of sand and gravel, asphalt roads would flow during hot weather and crack during cold weather.

The addition of sand and gravel to asphalt and concrete reduces their cost while improving their structural properties. Therefore, aggregate used in either application must possess a high compressive strength and must contain the proper mix of size fractions. In addition, to promote bonding with the concrete or asphalt, the aggregate must be crushed and washed to guarantee clean, fresh fracture surfaces. And finally, the aggregate should not be reactive. Large amounts of silicic volcanic rocks in concrete aggregate can cause serious complications associated

with moisture retention in the massive sections of concrete needed in large structures (Migues, 1985).

In Arizona most construction aggregate consists of sand and gravel which is mined from stream deposits or from terrace gravels near urban areas. Most production comes from gravel pits along the Salt and Agua Fria Rivers in the Phoenix metropolitan area and along the Santa Cruz River or its tributaries in the Tucson metropolitan area. In the Phoenix area the sand and gravel deposits are characterized by an excessive quantity of coarse fraction whereas in the Tucson area the deposits contain an excessive amount of the fine sand fraction. (Eyde, 1977).

Most other aggregate operations in smaller communities exploit deposits of sand and gravel in dry stream channels or alluvial deposits along the mountain ranges. Frequently, the quality of concrete or asphalt products which use the aggregate from these deposits is poor quality. Even though sand and gravel is the most abundant industrial mineral commodity in Arizona few deposits are suitable sources of nonreactive aggregate for large concrete structures (Migues, 1985).

The sand and gravel deposits in both Tucson and Phoenix contain siliceous Cenozoic volcanics and are, therefore, reactive. Consequently, sand and gravel used initially in the concrete for the Palo Verde Nuclear Generating Station had to be shipped from

deposits along the San Gabriel River in California when local deposits of aggregate were discovered to be reactive. The additional shipping costs increased concrete cost by \$178 million above the initial estimate (Lopez, 1985). As soon as the local aggregate sources were found to be reactive an investigation was started to locate non reactive aggregate resources closer to the generating station. The investigation discovered a deposit of non reactive aggregate about 150 miles west of the generating station on the western slope of the Gila Mountains north of Yuma, Arizona. This deposit supplied the bulk of the aggregate used in the construction.

Most large sand and gravel operations in the Phoenix and Tucson metropolitan areas produce several sizes of rock products ranging from coarse architectural gravel to fine reject sands used for back filling foundations. Aggregate producers add value to their product by making asphalt road mix and ready mix concrete. Thus the value of the aggregate in these products is substantially higher than the \$2.96 per ton indicated in the U.S. Bureau of Mines production statistics.

Aggregate producers in Arizona are facing several serious problems. First, sand and gravel resources are being urbanized. Second, the degradation of stream channels caused by the removal of sand and gravel has prompted legislation banning sand and gravel mining in stream channels. Third, the promulgation of a

single fiber standard mineral standard by OSHA for airborne particulates could place severe regulatory constraints on all operations particularly those in which the aggregate contains a high percentage of amphibole minerals. It appears that in the future more aggregate operations will exploit terrace gravels and some may begin mining and producing crushed stone products.

### Asbestos

Asbestos was the first high value-added industrial mineral produced in Arizona. Commercial exploitation of the deposits in central Gila County began in 1913 and continued at a rate of 1000 to 2000 tons per year until the Jacquays Mining Corporation closed their mines and mill in 1982. The closure was the result of litigation resulting from the contamination of a mobile park near the Metate Asbestos Company mill. The asbestos controversy is described in an excellent paper by Peirce and Garcia (1983).

Chrysotile asbestos is classified geologically as a metamorphic mineral and by end use as a physical mineral. It is used as a structural mineral in specialty asphalt roofing compounds, asbestos cement pipes, high temperature insulation and fire resistant textiles. As an extender filler, asbestos is used in friction products such as brake linings and other plastic resin systems. And finally, asbestos is a process aid when used as a filtration media.



Processed Arizona chrysotile asbestos products are low in iron. Consequently, the products were sold into high value-added specialty markets which included high temperature electrical insulation, plastic resin systems, and filtration media. Arizona asbestos products sold for the following prices in dollars per ton F.O.B. Globe, Arizona:

No. 1 crude (soft)	\$3000
AAA	2000
Grade 32 nonferrous filtering-plastic	1350-1400
Grade 4 T nonferrous filtering-plastic	700-1350
Group 7 white shorts	50-200

Source, Asbestos, January, 1981

Product prices depend on the fiber length, harshness, and iron content. Long, soft fibers command the highest prices.

The chrysotile asbestos deposits occur in the Apache Group of Precambrian age in the Mescal Limestone where certain beds are intruded by sills of diabase. Chrysotile occurs as cross-fiber veins within thin beds of serpentine. Veinlets as thin as one and a half inches thick have been mined. Subtle, hard to recognize structures such as monoclines, domes and folds may localize the veinlets of chrysotile (Keith, 1969). Virtually all of the production came from underground workings. The chrysotile veins were carefully cobbled and sorted at the mine.

Until the regulatory climate improves it is doubtful that asbestos production in Arizona will resume. Unfortunately, the hazard of asbestos exposure has been greatly exaggerated by regulatory agencies which have refused to differentiate between the fibrous serpentine mineral, chrysotile which is at worst a weak carcinogen and the fibrous amphibole mineral, crocidolite which is a carcinogen. It may take years before OSHA can adopt reasonable standards, because of the highly politicized and emotional responses to the issue. Hopefully, OSHA will eventually adopt multiple airborne mineral fiber exposure standards which are based on the disease producing potential of specific mineral dusts. These multiple exposure standards are in effect in Great Britain and other European countries.

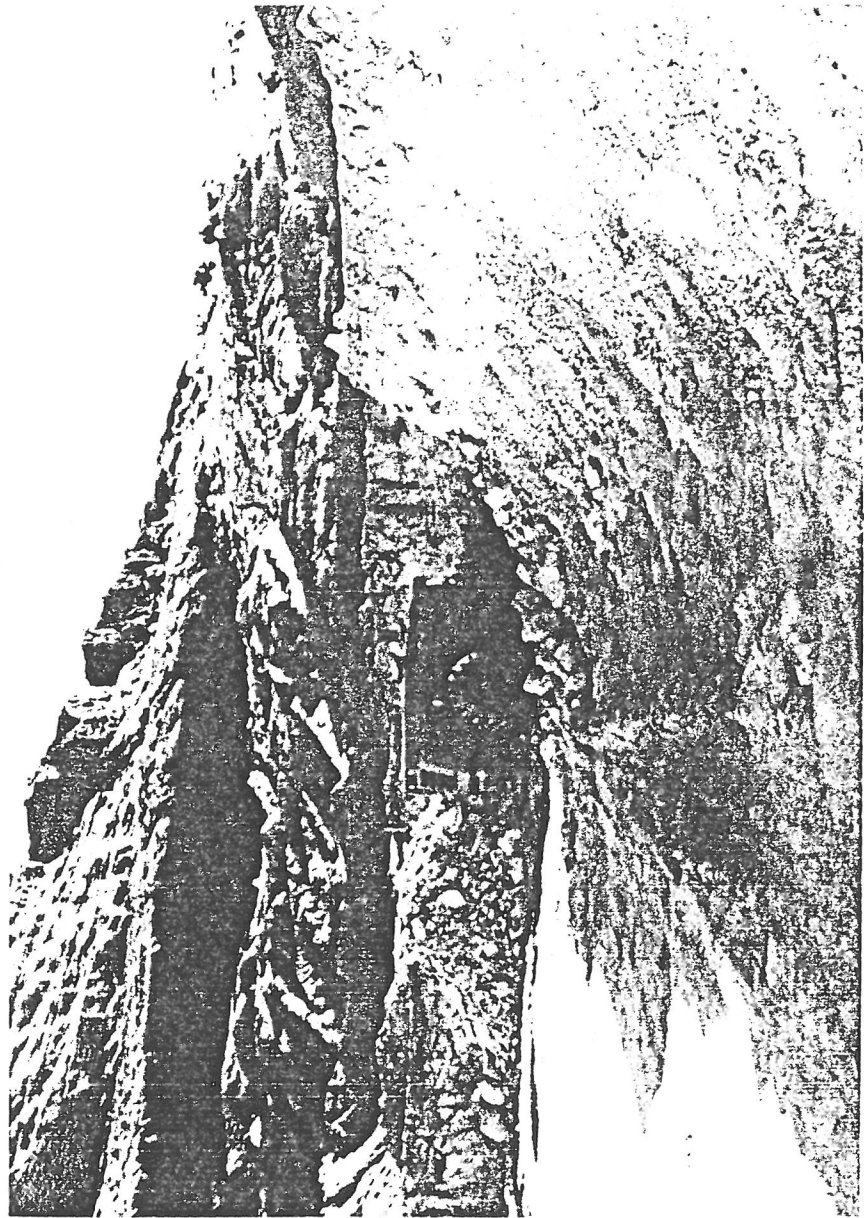
Even if this type of standard is adopted, reactivating the asbestos operations will require covered stockpiles, wet processing equipment, installation of dust collectors and a negative pressure system which prevents airborne particulates from escaping to the outside air. The cost of installing this equipment at an operation with gross sales of only \$1 to \$2 million a year seems unlikely.

### Bentonite

Bentonite was the second high value-added industrial mineral produced in Arizona. Commercial production began at the Allen-

town mine in 1924. The Chambers underground mine began production in 1926, and the surface mines at the Cheto deposit southeast of Sanders (Figure 7) began in 1933 (Kiersch and Keller, 1955). Most of the bentonite production was used in the production of acid-activated petroleum catalyst carriers. This end use application increased each year until 1957, when 270,000 tons of bentonite were produced. Bentonite was displaced by the introduction of synthetic zeolites in petroleum refining and bentonite production declined to a range of 25,000 to 40,000 tons per year. The crude clays are processed in New Mexico, California, and Mississippi into high value added desiccants which sell for \$700 per ton, acid-activated bentonites, thickeners and gellants which sell for \$2000 to \$3000 per ton.

Harben and Bates (1984) do not classify bentonite. Most bentonites result from the alteration of volcanic ash in lacustrine environments. Therefore, geologically bentonite could be classified as a surficially altered volcanic ash, as are sedimentary zeolites which have a similar origin. The end use classification indicates that bentonite is a physical mineral used in extender filler applications in such products as paints, printing inks, greases, and liquid soaps where the bentonite is a thickener or gelling agent. Cheto bentonite is a process aid when used as acid-activated bentonite for decolorizing edible oils and an absorbent when used as a desiccant.



The Cheto bentonite deposits which occur 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 which was deposited in the lakes in at least two horizons which range from less than a foot thick to over 10 feet thick. The bentonite is a remarkably pure dioctahedral montmorillonite member of the smectite group of clay minerals. It is the nearly monomineralic composition of the bentonite bed which results in its extraordinary sorptive properties (Eyde, 1985 a).

The most serious problem facing all of the operators in the district is the increasing overburden depth which now averages nearly 100 feet. Fortunately, in certain areas of the district a thick bed of hydrofrac sand occurs in the overburden. By selectively mining the sand during the stripping operations this resource can be processed into a salable product, which in turn reduces stripping costs.

### Cement

In 1984 the two cement plants in Arizona produced 1.5 million tons of cement. The older and larger plant is operated by Arizona Portland Cement at Rillito, 18 miles northwest of Tucson. The newer plant is operated by Gifford Hill and Company, Inc. at Clarkdale, 109 miles north of Phoenix. Cement is a

synthetic stone product composed of about 45% tricalcium silicate, 27% dicalcium silicate, 11% tricalcium aluminate, and 8% tetracalcium-aluminoferrite (Ames and Cutcliff, 1983).

At the Rillito plant limestone from the Martin, Escabrosa, and Naco, formations are the primary sources of limestone. The Martin Formation is also a source of silica and shale. These limestones are blended with aluminous clays from Pantano, iron ore, and gypsum from near Winkleman to manufacture cement (Rains, 1985). At the Clarkdale plant limestone from the Redwall limestone, and limestone, dolomite and clay from the Verde Formation are blended with slag or iron ore and gypsum from a deposit near Camp Verde to manufacture cement.

In Arizona the U.S. Bureau of Mines ranks cement a close second to aggregate in value of production. When compared with the mined value of the limestone and other raw materials which are blended to manufacture cement, this synthetic mineral product is a good example of value added through processing.

Because cement is a synthetic product Harben and Bates (1984) do not include it in their classification. Klein (1970) includes cement with the physical minerals and classifies it as a structural mineral. When cement is mixed with aggregate, another physical mineral that acts as a structural filler and adds strength to cement, the resultant product is concrete.

Most cement plants have been faced with the problem of cleaning up airborne particulate emissions. This has been done by covering stockpiles and utilizing dust collection equipment. Nevertheless, many cement quarries and plants would be faced with a serious problem in meeting airborne particulate standards if a single fiber standard is promulgated by OSHA.

### Clay

Clay used in structural applications is produced from two widely separated localities in Arizona. The high alumina clays from the Pantano deposit southeast of Tucson are used for making bricks and also as a source of alumina in cement production at the Rillito plant. The kaolinitic clay mined at a deposit near Pinedale is blended with aluminous shales and other mineral additives in the fabrication of vitrified pipe. Geologically, these clays are classified as clastic sedimentary rocks. Though structural clays do not appear in the end use classification, kaolinitic clays used in refractory and ceramic applications are categorized as ball clays which are chemical minerals. Certainly, all of these clays are in fact ceramic raw materials and should be classified as chemical minerals.

The clays being mined near Pantano occur near the base of the Pantano Formation of upper Oligocene to lower Miocene age. The clay beds range from a light to dark reddish brown color

and contain veinlets of satin spar, an fibrous variety of gypsum (Pennebaker, 1959). Experience has shown that the Pantano clays by blending, produce bricks exhibiting a wide range of colors after firing. The Pantano clays are blended with clays from Tolleson for brick manufacturing at the Phoenix Brick Yard.

The clays near Pinedale are kaolinitic underclays at the stratigraphic position of coal beds in the Cretaceous rocks (Morris, 1985). These clays do not contain calcite and therefore can be used for manufacture of vitrified pipe.

Vitrified pipe and bricks are both examples of value added by processing crude clays into fired or ceramic clay products. These ceramic products require both high purity raw materials. Thus, the ceramic clays mined at Pinedale and Pantano should not be classified as common clays.

### Feldspar

Feldspar production began from a pegmatite deposit in Precambrian granitic rock on the east side of the Cerbat Mountains north of Kingman in 1923. The Taylor mine suspended operations in the late 1970's after over 50 years of operation when the reserves available for surface mining were depleted. The milling facility operated until 1984 by grinding stockpiled quartz, a byproduct of the earlier feldspar mining operation. The geological classifi-



cation lists feldspar as an igneous intrusive mineral and the end use classification lists it as a chemical mineral used as a ceramic raw material.

Most of the feldspar produced from the Kingman operation was sold as a ceramic raw material. However, during the final years of operation some feldspar and all of the quartz were sold for abrasives in scouring powders. In this application both the the feldspar and quartz were physical minerals used as process aids.

It is doubtful that the feldspar mining and processing operation will resume unless the grinding plant is modernized and dust collection equipment is added. Further, the mine would require a major exploration program to evaluate the remaining feldspar resources. Even, if sufficient reserves are discovered, a major stripping program would be required before feldspar production could resume.

### Gypsum

Gypsum is produced from two widely separated deposits located in central and southern Arizona. Most of the gypsum production in Arizona comes from a deposit on the east side of the San Pedro Valley about 6 miles south of Winkleman, Arizona. In 1984 the district produced about 200,00 tons of gypsum used in wall board, Portland cement, and soil conditioners. A gypsiferous zone

occurs within a fine grained facies of the late Tertiary age Gila Conglomerate (Keith, 1969). Based on outcrops and drill hole information the basin occupies at least 18 square miles principally along the east side of the San Pedro River. The lacustrine section strikes N. 50 degrees W. and dips 3 to 7 degrees NE. (Hardas, 1966). An exploration hole drilled to evaluate one of the deposits, intersected a continuous 300 ft. thickness of interbedded clay and gypsum. Stratigraphic correlations between drill holes indicate that the section of interbedded clay and gypsum may be over 595 ft. in thickness (Shearer, 1985).

Aravaipa Creek bisects the deposit. North of the creek 30 to 50 ft. of massive gray gypsum with clay partings is being mined by National Gypsum company and the Superior Companies. South of the creek the Pinal-Mammoth Gypsum Company mines a surficial deposit of gypsite which has an average thickness of 5 ft.

At both the National Gypsum Company and the Superior Companies operations the gypsum must be drilled and blasted. The broken gypsum is loaded and hauled to crushing plants where the minus 3/8 inch fraction is screened off. At both operations the final product contains 90-92% gypsum and less than 4% insolubles.

The Superior Companies ship gypsum to the Arizona Portland Cement Company at Rillito where it is used as a cement retarder. National Gypsum ships the gypsum to their wall board plant in Phoenix. Crude gypsum used as a cement retarder sells for \$8 per ton F.O.B. the mine whereas wallboard sells for the equivalent of \$50-80 per ton of gypsum.

The Pinal Mammoth Gypsum company is the major producer of agricultural gypsum in Arizona. Gypsite containing 70 to 80% gypsum is scraped from the surface and pushed into stockpiles with a dozer. The crude gypsite is hauled to a screening and bagging facility at Coolidge, Arizona. The screened gypsite is spread on croplands, golf courses, and parks to reduce soil alkalinity.

The gypsum deposit being mined in central Arizona is southeast of Camp Verde. A thick gypsum-bearing zone in the Verde Formation of Miocene age which may be over 100 ft. thick is exposed at the mine. The gypsum is crushed and screened to remove the clay fraction before shipping to the cement plant at Clarkdale.

Geologically, gypsum is classified as a chemical precipitate. Gypsum can be classified according to end use as both a physical and a chemical mineral. As a physical mineral gypsum is used in wall board and joint cements. Both natural and synthetic gypsum are used as a high aspect ratio filler in resin systems as a

substitute for asbestos (Kusakawa,1982). As a chemical mineral, gypsum is used as a soil conditioner in alkaline soils and as a chemical process aid when used as a cement retarder. Gypsum production will continue to increase in Arizona as more homes and offices are built to accomodate a growing population. Most gypsum is consumed in construction applications in wall board, joint compounds, and cement.

### Limestone and Marble

Limestone and marble are grouped together because both are utilized in many of the same end use applications. Limestone and marble when crushed are used for road gravel, railroad ballast, concrete, asphalt and architectural aggregate and dimension stone. Both limestone and marble are used as flux stone and calcined into lime products.

Lime which is produced by calcining limestone is one of the major industrial minerals produced in Arizona. It is exceeded in tonnage and value only by aggregate and cement. At the Nelson operation which is east of Kingman, the Redwall Limestone is the source of the limestone for the kilns (Henderson, 1978). At the Paul Spur operation west of Douglas the Mural Limestone of Cretaceous age is the source of the limestone. Several of the

copper mining and milling complexes have produced limestone for both flux rock and calcined lime from deposits on their properties.

At both Nelson and Paul Spur the limestone is carefully explored by drilling to avoid zones of chert and dolomite. Chemical grade lime products must be 93.25 to 98.00% calcium oxide which demands stringent quality control during mining operations. (Boynton, Gutschick, Freas and Thompson, 1983).

Geologically, limestone is classified as a biogenetic sedimentary nonmetallic. Based on end use, lime is a widely used chemical mineral. It is used as a chemical raw material in the production of glass, soda ash, sodium bicarbonate, calcium carbide, and bleaches. Lime is used as a fertilizer raw material when used to treat acid soils. It is a chemical process aid in sugar refining, the flotation of sulfide minerals at metal mining and milling operations, in paper mills, and other manufacturing processes. Limestone is both a ceramic raw material and a metallurgical flux. When used in lime-cement mortars and plaster, lime can also be classified as a structural mineral.

Much of the lime produced in Arizona is used as a chemical process aid to adjust the pH of the flotation cells used to concentrate sulfide copper minerals in milling operations. The other major and growing use is in lime scrubbing units which

remove sulfur dioxide from the stack gases at coal-fired power plants. Limestone is used as flux rock at copper smelters.

Marble used as an architectural aggregate is now being produced from deposits in the southeastern part of the state. These operations exploit marmorized Paleozoic limestones which are in contact with Laramide intrusives. In 1985 the three producers were the Dragoon Marble Company operating the Ligier deposit south of Dragoon, the Andrada Marble Company operating the Andrada deposit in the Santa Rita mountains southeast of Tucson, and the Catalina Marble Company operating a deposit in the Tortolita Mountains west of Catalina. The marble at the Ligier deposit is marmorized Mississippian Escobrosa (Cooper and Silver, 1964), as is the Andrada deposit (Townsend, 1962). The Catalina deposit is developed in marmorized roof pendants of Permian Concha limestone.

The marble from these deposits is used for architectural aggregates in applications such as roofing granules, terrazo, ground cover, and concrete facing panels. At the quarries the marble is sorted by color and then crushed to the size required for the specific end use application. Marble used in applications where it is exposed to weathering cannot contain pyrite which alters to limonite and stains the marble.

Sales of crushed marble are closely related to building activity. In an area such as southern Arizona which is growing rapidly, the consumption of crushed marble will continue to grow. Nevertheless, improvements in roofing materials such as foam and reflective coatings which are both lighter and more energy efficient than marble decorative stone have reduced the consumption of marble for this application. The consumption of marble for ground cover in residential areas will continue to increase as the cost of watering lawns increases.

Contact metamorphic deposits of marble such as those in Arizona should be carefully evaluated for the presence of tremolite. Often tremolite is difficult to identify in high-purity white marble, in particular the fine grained varieties. Because of its high aspect ratio and fibrous habit OSHA has classified tremolite as asbestiform (Thompson, 1984). Clearly, the presence excessive amounts of tremolite in marble could increase the producer's potential exposure to product liability lawsuits.

### Perlite

The first commercial production of perlite in the United States came from the deposits on the east side of Picket Post Mountain southwest of Superior, Arizona. In 1984 the district produced an estimated 50,000 tons of sized-unexpanded and crude perlite.

Perlite is mined from the perlite facies of the Tertiary age Arnett rhyolite (Crosswhite, 1984). The perlite horizon mined ranges from 5 to over 100 ft. thick. Guzman Construction Company produces crude crushed perlite for processing in Arizona. Harborlite and Silflo crush, screen, and dry the perlite in processing facilities west of Superior. The sized perlite products are shipped out of state for expansion or "popping" into a light weight cellular aggregate (Kadey, 1983).

Geologically, perlite is classified as an extrusive igneous rock. According to end use, perlite is classified as a physical mineral. It is a structural mineral when used as a light-weight aggregate in concrete and in prefabricated light-weight roofing panels and board used in commercial building construction.

The expanded products, depending on the particle size and density, are used in formed construction products such as ceiling tile, roof insulation board, and pipe insulation; horticultural aggregate; loose fill insulation; and light weight aggregate. Several high-value added products are prepared by grinding and sizing the expanded perlite. These include filter aids and fillers. Attrition milling of the expanded product comminutes the perlite particles into a high aspect ratio, low bulk density cellular filler. Surface modified perlite is now used as a filler in engineering plastics.



In 1985, sized, unexpanded perlite sold for \$39 per ton F.O.B. the plant. The expanded products sold for \$165 per ton. The attrition milled high aspect ratio products sold for over \$250 per ton. Perlite is an excellent example of how value can be added by additional processing.

### Salt

The Luke Salt body which underlies Litchfield Park is exploited by solution mining. The salt deposit which is of late Miocene age consists of at least a 4500 ft. thickness of halite. Its complete lateral extent is not known. The halite deposited as an evaporite facies in a local structural basin. There appears to be some evidence of some upward salt movement (Pierce, 1974). The Luke Salt is composed of nearly pure halite which contains only traces of the blocking ions magnesium and calcium.

Geologically, salt is classified as a chemical nonmetallic. Classified by end use it is a chemical mineral when is used as a chemical raw material and a chemical process aid.

In 1985 the operation at the Luke Salt deposit was the only producer in Arizona. Morton Salt Company which purchased Southwest Salt Company in 1985 uses solution mining to produce brine from the Luke salt. Solar ponds concentrate the brine to a saturated solution. In this environment the salt precipitates

forming a layer of salt on the bottom of the ponds which is then removed by a salt harvesting machine. The crude salt is brine--washed to remove the insolubles and traces of magnesium and calcium and then allowed to dry (Grott, 1985 a). It is shipped in bulk or bags to the users.

The salt because of its low magnesium and calcium content is a specialty product which in 1985 sold for \$40 per ton. It is used as a chemical raw material in the production of chlorine swimming pool chemicals, and as a chemical process aid in tertiary oil well recovery fluids, and domestic and industrial water softeners.

Higher purity chemical raw materials are being demanded by the consuming industries. Today the cost of disposing of the waste brines from chlorine production often exceeds the cost of the raw materials. The amount of waste products generated can be reduced significantly by using high-purity chemical raw materials. This in turn reduces manufacturing and processing costs. At the Luke Salt deposit three solution cavities are now leased to Cal Gas for the storage of propane and butane. All the waste brine and solids from the brine washing operation are reinjected into the salt through an injection well.

## Sand

Sand production from deposits in the Houck area began in 1961. Although 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. The deposits of proppant sands were derived from Permian sandstones and deposited in a deltaic environment where streams draining the Defiance Plateau entered a series of lakes along its west side. The sands are confined to the Bidahochi Formation of Pliocene age (Eyde, 1985).

These sand deposits would be classified as clastic sedimentary nonmetallics. Klein (1970) does not have a category listed for hydrafrac sands. However, it would appear that proppant sand is a physical mineral which could be classified as a structural mineral because it props the fractures open allowing oil and gas to flow into the well bore.

The hydrafrac sand product is the minus 20 plus 40 mesh fraction. It contains about 97% silica, has a roundness of 0.6 to 0.7 on the Krumbein scale and a low acid solubility. Oil well service companies use about 40,000 tons per year completing oil and gas wells in the Farmington, New Mexico area. This is a high valued added specialty sand product which in 1984 sold for over \$25 per ton (Norman, 1979).

Production from the deposit at Houck is restricted because homes have been constructed on the westward extension of the deposit. Similar sand deposits overlie the bentonite deposits at the nearby Cheto bentonite deposit. These deposits may ultimately provide sand for the plant at Houck.

### Scoria

Scoria is the mafic counterpart of pumice. It is a rusty red to black pyroclastic material of andesitic to basaltic composition which forms many volcanic cinder cones (Harben and Bates, 1984). Scoria, referred to as pumicite (Keith, 1969) has been mined in the Flagstaff area for many years. Scoria is classified as igneous extrusive which is a physical mineral used in structural applications. Because of its high porosity and light weight, scoria is used extensively in the manufacturing of lightweight concrete cinder blocks.

Blocks made from scoria must have an acceptable compressive strength. One major advantage of using the basaltic and andesitic scorias in concrete blocks is that basic volcanics are less likely to be reactive aggregates which could cause the deterioration of the blocks. Therefore only a few deposits contain scoria which can be used for the aggregate in lightweight blocks. The principal problem encountered in scoria production has been

the perception by the public that all scorias are identical. This has resulted in attempts to stop the mining of good quality scoria in areas which are highly visible.

### Zeolites

Zeolites have been mined since 1961 from a deposit of chabazite north of Bowie, Arizona. This is the largest known deposit of high purity chabazite in the United States, if not the world.

Geologically, sedimentary zeolites would be classified as surficially altered minerals. Zeolites are physical minerals when used as process aids, in adsorption, catalysis or cation exchange applications. The chabazite from Bowie is used mainly as a specialty adsorbent for treating sour natural gases. It has also been used to remove by cation exchange the radioactive isotopes Cesium 137 and Strontium 90 from nuclear reactor waste streams (Sheppard, Gude, and Edson, 1978).

The principal producer of chabazite from the Bowie deposit is the Linde Division of Union Carbide Corporation. Their molecular sieve product AW 500 is a specialty adsorbent used to remove carbon dioxide, water, and hydrogen sulfide from methane. Their ion exchange products are IE 95, an unmodified chabazite ion exchange product, and IE 96, a calcium-modified ion exchange product. Both products were used to remove radioactive cations

from the water in the basement of the reactor building at Three Mile Island, Pennsylvania (Collins, Campbell, King and Knauer 1982). In 1985 AW 500 sold for \$ 2.50 a pound and the IE 95 and IE 96 for a somewhat higher price.

The zeolite horizon is a vitric tuff that altered in a saline-alkaline lake to the minerals chabazite, erionite, and clinoptilolite. It is enclosed in the Green Lake Beds which are believed to be Plio-Pleistocene in age. The deposit is exploited by surface mining techniques which recover the lower massive or "high grade bed" which is about half a foot thick. All of the production is shipped out of state for grinding prior to extrusion and activation. The deposit supplies a growing market for specialty adsorbent and ion exchange products.

#### Future Developments

Increases in both the standard of living and in population in the southwestern United States will certainly stimulate the demand for industrial minerals. Both the quantity and the type of industrial minerals produced will increase. Exploration for deposits of specialty clays such as the bentonites used as viscosifiers, stabilizers, in edible oil clarification, and desiccants will increase. So too, will exploration for extender-filler minerals such as wollastonite and mica. The demand for

high purity salt and sodium sulfate will increase as the cost of disposing of waste brines increases.

Research into the utilization of the storehouse of all-ready ground mine tailings will increase. For example one of the largest resources of rutile, which is used in the manufacture of titanium dioxide pigments, are the tailings at San Manuel (Force, E.R., 1981). These tailings contain extensive resources of quartz, mica, and feldspar all of which it may be convertible into marketable high-value added industrial mineral products.

The only cloud on the horizon is the effect of public land and environmental policy on the exploration, development, and production of industrial minerals. Valuable deposits of industrial minerals are often not recognized and as a result are included in wilderness areas or are urbanized rendering these resources unavailable. Equally serious is the attempt to establish a single fiber standard for airborne particulates. Imposition of this standard would be a disastrous attempt at legislating against Mother Nature.

The 152 fibrous varieties of minerals would all be considered asbestiform based entirely on particle shape. Imposition of this standard would close many mines, quarries, and gravel pits and result in significant increases in the prices of mineral products marketed by the remaining producers.

With reasonable land use and environmental regulation, the production of industrial minerals in Arizona will continue to increase. Assuming this occurs, the value of industrial minerals production could exceed that of copper by the end of the century.

Arizona Industrial Minerals Deposits  
Which May Be Productive In The Future

Bentonite

A major deposit of high-magnesium bentonite occurs along both sides of Burro Creek About 8 miles west of Bagdad. Several bentonite horizons occur within a tilted section of Miocene lacustrine beds. The bentonite horizons contain both saponite and trioctahedral smectite clay.

The beige-colored bentonite clay because of its high brightness, color and purity has potential applications as a high unit value thickener and stabilizer used in paints, greases, pharmaceuticals, and cosmetics. The bentonite is reported to have commercial potential as a raw material for producing stabilizers and thickeners with relatively unsophisticated treatment (Schreiner, 1985).



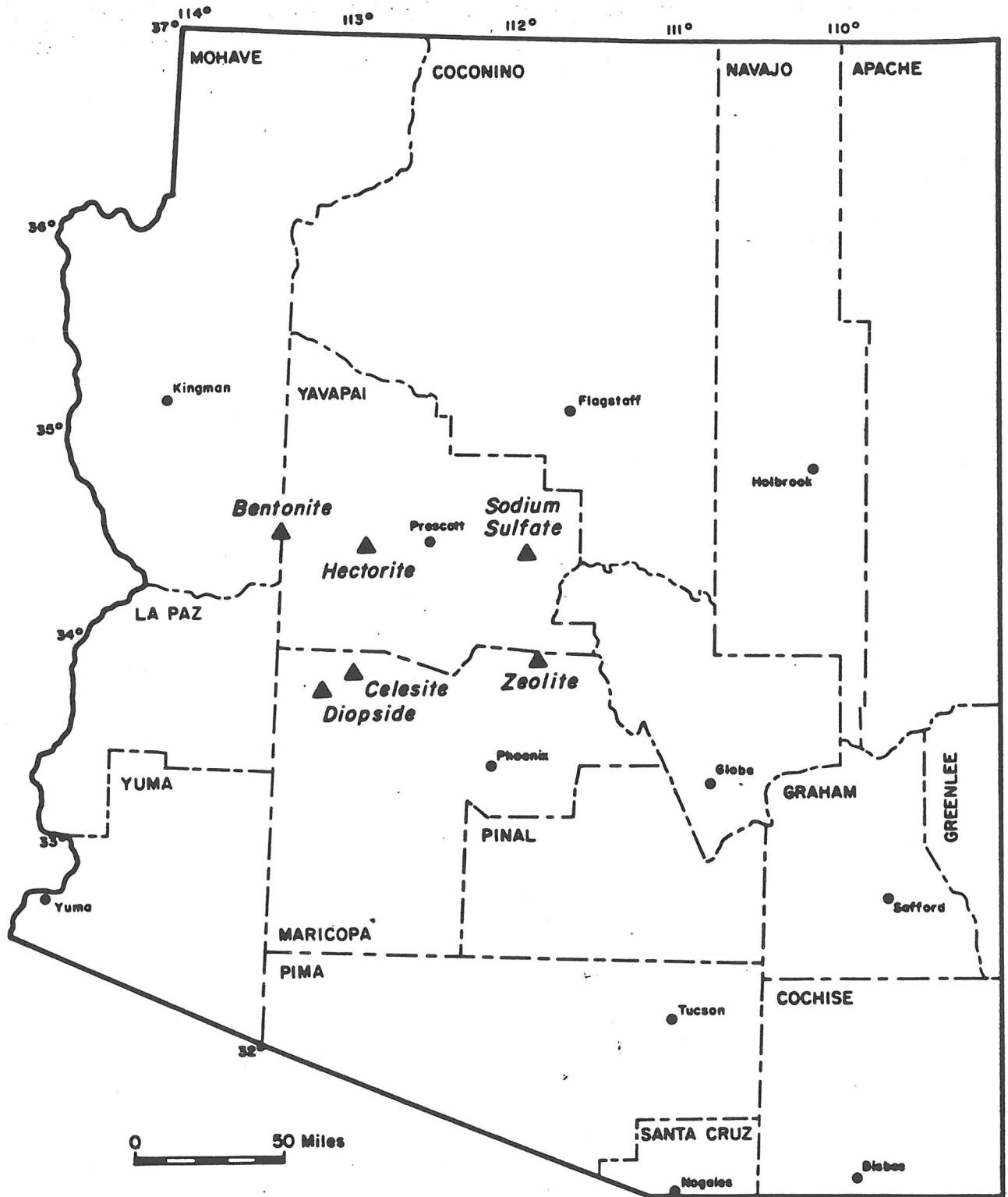
The highest purity smectite and saponite occur near the contact of linear travertine masses that appear to be localized along faults. It appears that the bentonites are a result of the alteration of the lacustrine beds by thermal spring waters. Chalcedony and dolomite concretions occur within the saponite and smectite horizons.

It would appear that the deposit would be classified as a surficially altered industrial mineral. The parent bentonite appears to be the alteration product of a volcanic ash which was subsequently altered by hydrothermal solutions. Based on the end use as thickeners and stabilizers the bentonite would be classified as a process aid.

The deposit is adjacent to and within the Lower Burro Creek Wilderness Study Area. The final location of the permanent boundary of the WSA will determine whether that portion of the deposit on the west side of Burro Creek will be brought into production.

### Diopside

A unique deposit of diopside occurs about 18 miles south of Aguila near Sunset Canyon in the Harquahala Mountains. The diopside occurs in a contact metamorphosed section of Paleozoic limestone. An exposure of the diopside bed in a pit indicates



MAJOR ARIZONA INDUSTRIAL MINERALS DEPOSITS WHICH  
MAY BE PRODUCTIVE IN THE FUTURE

that the bed consists of a 12 ft. thickness of coarsely crystalline white diopside. The bed strikes east and dips about 20 degrees north and can be traced several hundred feet along the strike (Matson, 1985).

According to Funnel and Wolfe (1964, p.98) the diopside deposit was known as the Yellow Flower mine. Diopside from the deposit was shipped to California for use in ceramics (Davis, 1967, p. 148). The deposit has not been productive for many years.

Diopside is a metamorphic mineral whose end use application is as a chemical mineral in ceramics. Apparently, because of its chemical composition, a calcium, magnesium, silicate and fibrous habit, diopside improves the thermal shock resistance of ceramics. R. T. Vanderbilt Company, Inc. has considered producing diopside from a small deposit at their Gouverneur talc deposit in New York for specialty ceramic applications (Thompson, 1985). It appears that the Yellow Flower diopside deposit may be developed as a source of a specialty ceramic raw material.

### Celestite

An important deposit of celestite occurs in the Vulture Mountains about 15 miles south of Aguila near Black Butte. The celestite-bearing beds which are at least 156 ft. thick occur in a westerly

dipping section of Miocene lacustrine beds. Both the massive and shaly horizons contain celestite.

Two samples collected at the deposit contained 85.3 and 73.1 percent celestite (Moore, 1936). Three samples of individual beds ranging from 3 to 10 ft. thick analyzed by Chemical Products Corporation contained 61.4, 73.1, and 69.9 percent celestite (Bearden, 1983). The celestite appears to be fine grained and will require fine grinding prior to flotation.

The celestite deposit appears to be an evaporite which Harben and Bates (1984) classify as a chemical nonmetallic. The end use applications of the celestite which is converted to strontium carbonate are in the glass radiation shields of color television sets, permanent magnets, greases, soaps, lubricants, and paints. In these applications the celestite is classified as a chemical mineral.

The Black Butte celestite is one of the major celestite resources in the United States. Nevertheless, its purity is much lower than the productive deposits in Mexico, Turkey, and Spain. Development of this deposit is being considered to provide an alternative source of celestite in the event the foreign supplies are cut off.

## Hectorite

The Lyles hectorite deposit is one of only three deposits producing hectorite in the United States. The others are at Hector, California operated by N. L. Chemicals and Invite, Nevada operated by IMV (Industrial Minerals Ventures) a subsidiary of Gulf Resources and Chemical Corporation. Sometime during the mid 1950's Joseph Lyles of Yarnell discovered that the clay from the deposit contained detectable amounts of lithium. He brought the property to the attention of E. T. Turley of Phoenix, Arizona who explored the deposit with pits and auger holes. Later Mr. Turley mined hectorite for use as a sealant for irrigation ditches and stock ponds (Norton, 1965).

The James Stewart Company of Phoenix which was interested in the deposit as a source of lithium, acquired the deposit during the early 1960's. In 1982 GSA Resources acquired the deposit and began a drilling program to evaluate the hectorite deposit. Bulk sampling and pilot plant testing were completed in 1985. The first shipment was made from the deposit to a specialty clay producer in 1986.

The deposit according to Harben and Bates (1984) would be classified as a surficially altered deposit. The hectorite horizon is interbedded within a section of lacustrine clays at least 70 ft. thick which is overlain by a 1 to 2 ft. thick bed

of vitric tuff zeolitically altered to phillipsite. Another bed of vitric tuff zeolitically altered to clinoptilolite occurs below the hectorite bed. The zeolite beds are excellent marker horizons.

The hectorite bed is 8 to 35 ft. thick. It is both overlain and underlain by high alumina smectites. The hectorite when freshly mined ranges from a translucent waxy white to light yellowish white color. In fact, much of the hectorite actually resembles white candle wax (Figure 9).

The hectorite horizon contains large concretions of chalcedony and dolomite. It appears that the hectorite in fact is a hydrothermal clay deposit. A travertine mass crops out in the valley along the east side of the deposit. The relationship between travertine masses and high magnesium smectite has been noted at both the Invite and Hector deposits as well as at other deposits of saponite and high magnesium smectite.

The deposit appears to have formed when thermal spring waters rich in magnesium were introduced into the normal high alumina smectite clays in the lacustrine beds. The existence of the thermal springs is strongly suggested by the travertine deposits which are usually linear, vein-like structures. The hectorite bed actually may be the result of magnesium metasomatism of a high alumina smectite clay horizon. The silica and dolomite

concretions may indicate the migration of thermal waters through the hectorite bed.

Hectorite is a physical mineral when used as a thickner and viscosifier in many products such as paints, saltwater drilling muds, and liquid shampoos. Some hectorite products are organoclad with quaternary compounds which make the hectorite organophillic. Organoclad hectorite is used in thickeners and viscosifiers in oil based paints, greases, oils, and oil based drilling muds. In 1985 organoclad clay products such as the Bentones, and Benagels produced by N. L. Chemicals sold for over \$1.00 per lb.

### Sodium Sulfate

The Camp Verde sodium sulfate deposit has been known for at least 2000 years. In fact, it may be the oldest mine in the State of Arizona. Evidence of pre-Columbian activity which included artifacts and the mummified remains of a miner were discovered when the mine was operated during the 1920's. The Spanish explorers Antonio de Espejo in 1583 and Marcos Farfan de los Godos in 1598 are both believed to have visited the mine (Barlett, 1942).

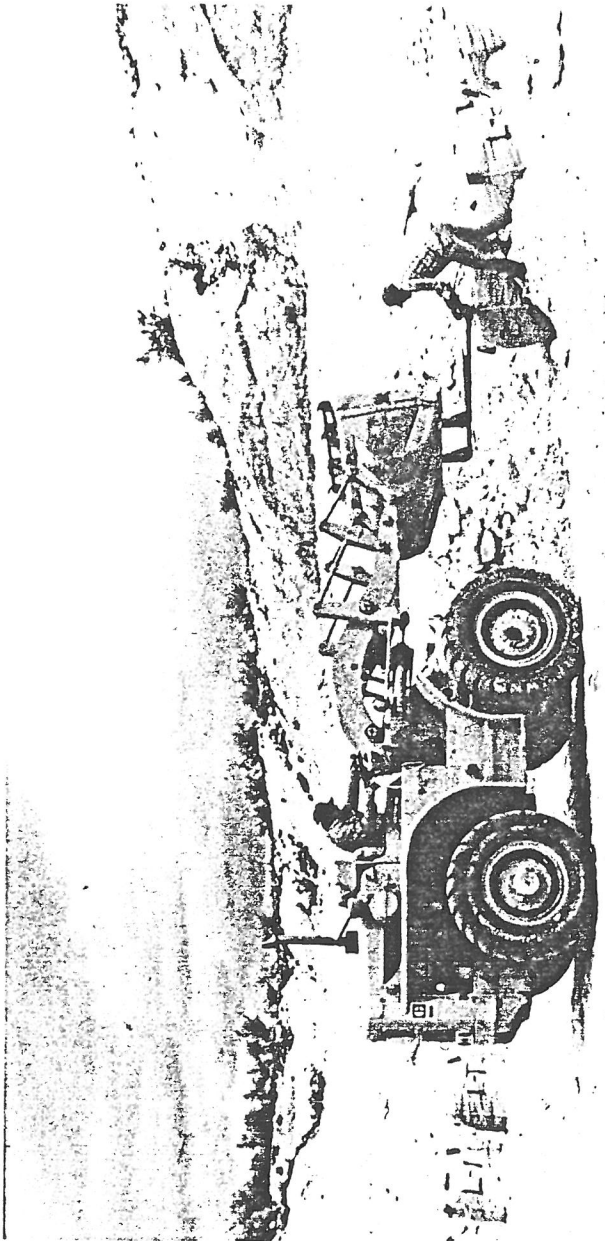
The evaporite sequence which consists of halite, mirabilite and glauberite is as much as 46 ft. thick at the Camp Verde Salt Mine. The evaporites grade into gypsum and halite in the deeper part of the basin southeast of Camp Verde (Thompson, 1983). The

Superior companies mine gypsum from a deposit in the gypsiferous facies and ships it to the Gifford Hill and Company Inc. cement plant at Clarkdale, Arizona. Aragonite crystals and more rarely needle-like pseudomorphs of glauberite can be found on the high wall along the west side of the old pit. Beautiful acicular crystals of mirabilite can be found in the drainage ditches. Sodium sulfate is classified a chemical nonmetallic based on its geological classification.

The Verde formation which hosts the evaporites consists of at least 1600 ft. of sediments. It is believed the basin formed during Oligocene time possibly as a result of movement along the Verde fault zone. During Miocene time the drainage through the south end of the valley was blocked by volcanics resulting in a closed basin in which a saline-alkaline lake formed. When the Verde River breached the volcanics during Pleistocene the resultant erosion exposed the evaporites.

Western Chemical Company began surface mining operations during the 1920's to exploit what was believed to be the largest deposit of sodium sulfate in the world. In the early 1930's Arizona Chemical Corporation a joint venture between American Cyanamid and International Paper Company acquired Western Chemical Company. Underground mining was started using room and pillar mining methods.





The crude sodium sulfate-halite mined underground was transported to the processing facilities on a conveyor belt. About 100 tons of salt cake, anhydrous sodium sulfate, was produced per day making it the largest producer in the United States (McDermid, 1934). The mine closed in 1933 when low priced high purity sodium sulfate from Germany began entering the United States. Some exploration drilling was done on the sodium sulfate deposits in the Camp Verde area by Stauffer Chemical Company in the 1960's but the mining operation was not reopened (Grott, 1985 b).

Sodium sulfate which is classified as a chemical mineral is used as a process aid in the manufacture of kraft paper pulp which is also known as sulfate pulp. About 88 lbs. of sodium sulfate is used to produce a ton of kraft paper pulp.

Another major and fast growing use of sodium sulfate is in washing detergents where it is a noncorrosive, neutral, and cheap filler with mild detergent properties. The other principal use is in flat glass production. The major markets for sodium sulfate in the United States are:

Kraft paper pulp	55%
Detergents	35%
Glass	5%
Other uses	5%

In 1984 sodium sulfate sold for \$90 - 96 per ton in carload lots F.O.B. the processing plant.

The Camp Verde sodium sulfate deposit could be reactivated as the use of sodium sulfates in detergents particularly liquid soaps increases. There are many sources of sodium sulfate available as by products from the manufacturing of hydrochloric acid, rayon, and other chemicals which compete directly with natural sodium carbonate. Still, natural sodium sulfate has captured over half the market in the United States (Weisman and McIlveen, 1983).

### Zeolites

The largest known high purity deposit of the zeolite mineral clinoptilolite in Arizona occurs near Horseshoe Dam on the Verde River about 55 miles northeast of Phoenix. At least 6 beds of clinoptilolite which range from 2 to 18 ft. thick are interbedded in a section of Miocene lacustrine beds which strikes N. 50 degrees W. and dips 50 degrees SW. The main zeolite bed which is 9 to 18 ft. thick and crops out continuously for 5000 ft. contains over 80 percent clinoptilolite (Eyde, 1963).

The clinoptilolite is classified as a surficially altered mineral. It is unique because the clinoptilolite contains 1.5 percent strontium which has replaced some of the calcium in the crystal lattice. This substitution appears to have made the pore size of the clinoptilolite large enough to allow oxygen adsorption. The clinoptilolite from the Horseshoe Dam deposit is the

only deposit of this mineral in the United States known to adsorb oxygen (Breck, 1963).

Bulk samples of the clinoptilolite from the deposit have been used successfully as deodorizers and cation exchange media for ammonia nitrogen removal. Because of its high brightness and uniform particle size the clinoptilolite has been found suitable for paper filling. This clinoptilolite could also be used as a filler-catalyst used in the production of reinforced plastic resins from mixed plastic scrap (Choparinov, Filizova, Kirov, 1985). In all of these applications the clinoptilolite would be classified as a physical mineral used as a process aid or as a structural mineral in filler applications.

Much of the Horseshoe Dam clinoptilolite deposit is within a withdrawal for a reservoir site and irrigation works on the Verde River. This temporary withdrawal occurred in 1903 long before the economic potential of zeolites and other industrial minerals was recognized. This is an excellent example of how withdrawals which occur before applications such as pollution abatement even existed can prevent a mineral deposit from being mined (Eyde, 1978, p. 5). Development of this deposit could be impeded if not prevented by this withdrawal.

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Arizona Industrial Minerals,  
A Growing Industry in Transition

List of Illustrations

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