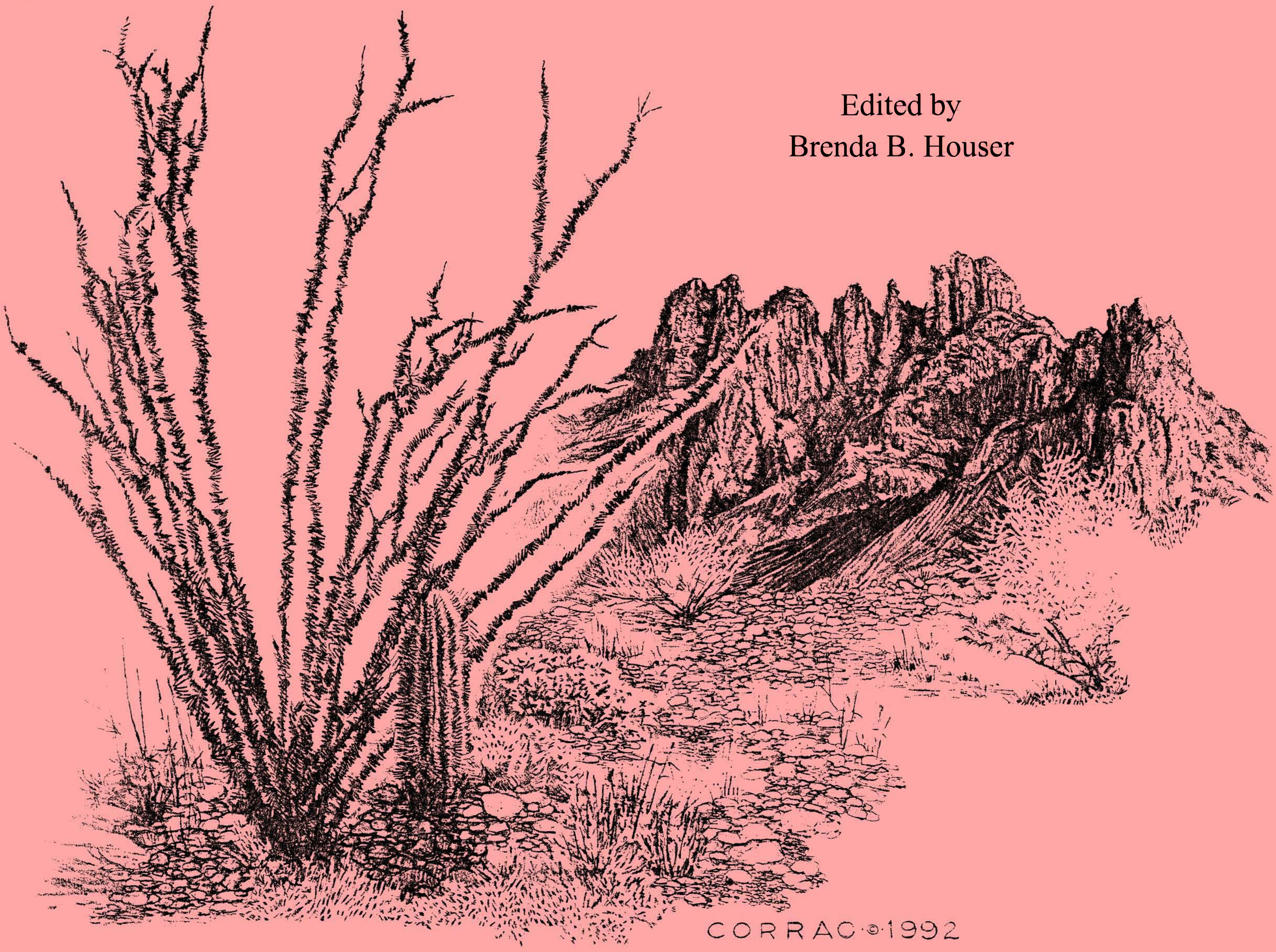
Industrial Minerals of the Tucson Area and San Pedro Valley, Southeastern Arizona

Edited by
Brenda B. Houser



Arizona Geological Society Field Trip
April 4 and 5, 1992

Arizona Geological Society
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Tucson, Arizona 85717

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Arizona Geological Society
Industrial Minerals Field Trip
April 1992

Introduction

The April, 1992 field trip of the Arizona Geological Society focuses on industrial rocks and minerals of the Tucson area and nearby San Pedro Valley, southeastern Arizona (fig. 1). We are fortunate in that, because of the geologic setting of southeastern Arizona in the Basin and Range province, a wide variety of industrial rocks and minerals occur within easy driving distance of Tucson. The deposits range in age from Precambrian through mid-Tertiary in the mountains and from mid-Tertiary to Recent in the basins. Ken Phillips (this volume) has summarized the mineral economics of the industrial rock and mineral commodities that will be seen on this field trip.

The first morning's stops are plant tours in the Tucson area of the Arizona Portland Cement computerized processing plant, the Tanner Rock and Sand Company's aggregate processing facility, and the Pima County Materials Testing Laboratory. These plants and laboratories reflect a major part of the nation's minerals output and one that is critical to America's infrastructure (Guilbert, road log, this volume).

In the afternoon of the first day, we will visit two marble quarries in contact metamorphosed Paleozoic limestone in the northern Santa Rita Mountains. Both operations have been acquired recently by large national and international companies. The history of these and other marble quarry acquisitions in Arizona is given in the paper by Eyde and Eyde (this volume).

The last stops of the first day are in Cienega Gap where the mid-Tertiary Pantano Formation and an overlying younger rock-avalanche deposit are exposed. Both the Phoenix Brick Company and the Arizona Portland Cement Company obtain clay from the Pantano Formation at Cienega Gap. The unique properties of the clay here make it valuable enough to offset transportation costs (Eyde, road log, this volume).

The second day of the field trip concentrates on the San Pedro Valley. In the morning, we will see deposits that are interbedded with the Quiburis Formation, a Neogene basin-fill unit of the San Pedro basin. The first stops are at the White Cliffs diatomite deposit, an upper Miocene lacustrine deposit within the Quiburis Formation. At about midday, we will visit the Gold Bond gypsum quarry, also in the Quiburis Formation. Shenk (this volume) has described the diatomite and gypsum deposits and summarized the geology of the San Pedro basin.

The afternoon stops are at bedrock exposures on the west side of the San Pedro Valley. The first stop is at an occurrence of asbestos minerals, similar to the Salt River Canyon asbestos deposits, exposed in Precambrian Apache Group rocks in Putnam Wash opposite the mouth of Aravaipa Creek. Some of the problems concerning the genesis of Salt River Canyon type asbestos deposits are discussed by Guilbert (road log, this volume). Next we will visit a quarry in the Apache Group Troy Quartzite nearby on the north side of Putnam Wash. The quartzite is shipped to the smelter at San Manuel.

The final stop of the day will be at a landscaping materials deposit that overlies the Kalamazoo ore body. The history of the Kalamazoo deposit is given by Hockett in the field trip road log (this volume).

Brenda B. Houser
Vice President for Field Trips, 1992
Arizona Geological Society

Geologic Highlights and Road Log

Day 1 - Morning

Plant Tours in Tucson - John M. Guilbert

The first morning of our two-day field trip will provide a view of the biggest mining sector in the country; the production of cement by the calcining of crushed limestone (cement rock) coupled with the mining, washing, and sieving of sand and gravel, chiefly for aggregate in concrete. These two activities account for about 38 percent ($12.5 billion in 1990) of the dollar value of American mining!

We will first visit the Arizona Portland Cement Company's Rillito plant to see how the cementitious part of concrete (the binder, the matrix) is mined and manufactured. Second, we move on to the Tanner Companies' sand and gravel plant to see a sand and gravel quarry and its processing equipment, whereby the material that gives concrete its bulk and strength is produced. Finally we will make a brief stop at the Pima County Materials Testing Laboratory to see how we ,as citizens, are assured that the concrete that results from the combined efforts of Arizona Portland and Tanner meets safety and physical requirements, and to get a feeling for what poured, set concrete really looks like...and is. (J.M.G.)

Mileage	Comments
0.0	U of A red-permit parking lot at the southeast corner of Euclid and E. 4th St. Go north on Euclid to Speedway Blvd. (0.4)
0.4	Junction of Euclid and Speedway Blvd. Go left (west) on Speedway to I-10. (1.4)
1.8	Junction of Speedway Blvd. and I-10. Go right on westbound I-10 to Avra Valley-Rillito exit. (14.0)

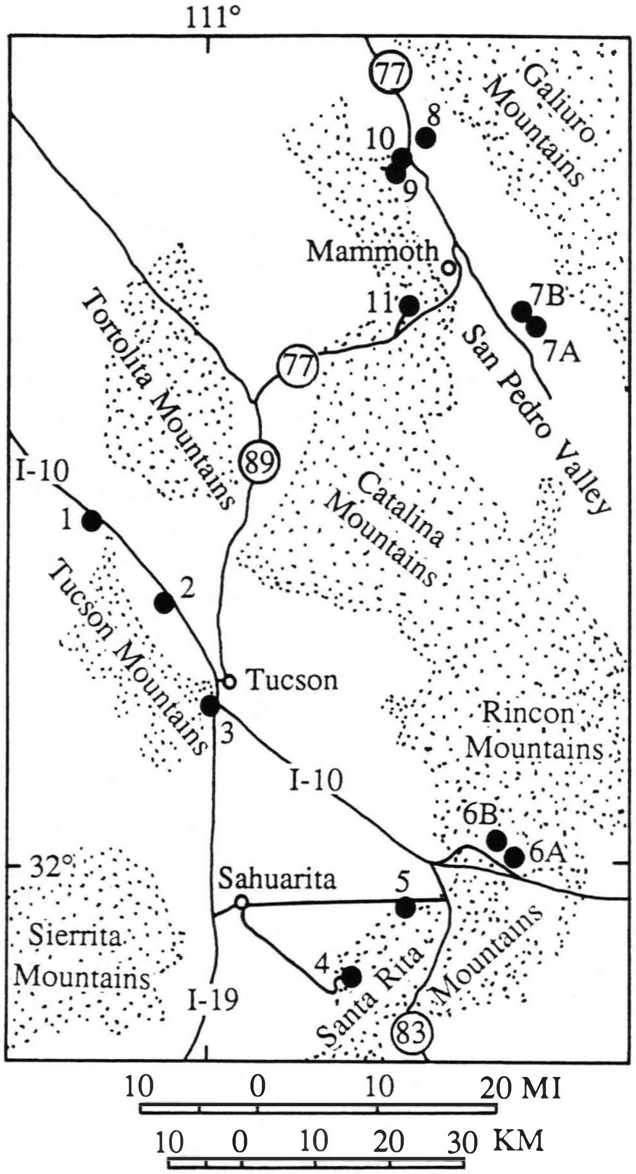

Figure 1.--Map showing field trip stops of the 1992 Arizona Geological Society Industrial Minerals Field Trip, Tucson area and San Pedro Valley, southeastern Arizona.

The Tucson Mountains to the west consist chiefly of Upper Cretaceous volcanic rocks that recently have been interpreted to be the fill of a large ash-flow caldera (Lipman and Sawyer, 1985; Lipman and Fridrich, 1990). The Cretaceous volcanics are overlain by mid-Tertiary (19 to 28 Ma; Bikerman and Damon, 1966) basaltic andesite lavas on

Sentinel Peak (A Mountain) and Tumamoc Hill. This rock was one of the first industrial rock commodities to be utilized in the Tucson area. In prehistoric times the Indians used the talus boulders to build low retaining walls on Tumamoc Hill, possibly for agricultural terraces, and in the late 1880's Mexican teamsters quarried the bouldery talus on the south and northwest sides of Tumamoc Hill for the walls and foundations of Tucson houses (Wilcox and Larson, 1979).

The Santa Catalina and Tortolita Mountains on the east comprise the mid-Tertiary Catalina core complex (Spencer and Reynolds, 1989; Dickinson, 1991). The rocks of the core complex are chiefly Precambrian, Laramide, and mid-Tertiary granitic rocks and minor exposures of Pinal Schist, Apache Group rocks and 1.2 Ga diabase dikes. There are no rock quarries on the southwest side of the Santa Catalinas or Tortolitas. Boulders of mylonitic granite are commonly saved at construction sites in the Foothills area and used in landscaping.

15.8 Avra Valley exit ramp. Cross beneath I-10 on Avra Valley Road and turn right (north) on road to Rillito. (1.7)

17.5 Turn left at entrance to Arizona Portland Cement and park in parking lot on right.

Stop 1 Arizona Portland Cement Company, Rillito Plant.

Hardhats required.

Ross Smith, our host, will meet us at the office building. We will receive a handout or two at the plant, but here's some additional perspective on the technology of concrete. The operation consists of these parts:

* the quarry
* the primary crusher and storage-surge building
* the 3.9-mile conveyor belt system from quarry to plant
* the stacker-reclaimer blending-storage building
* the kiln-feed composition-adjustment system
* the kiln
* the cement milling-bagging-trans shipment system.

Interesting aspects to these components are:

* grade control in the pit
* the analytical XRF control system
* the heat-conservation--pollution control system
* automation of the integrated process.

Recall that cement (the dry gray stuff in the bags at the lumber yard) is not just calcined limestone. Portland cement has a specific oxide composition in the ternary system CaO-Al_20_3-$Si0_2$, with very strict specifications on components such as FeO, MgO, TiO_2, and especially the alkalies K_20 and Na_20. When water is added to cement, micro-tubular synthetic minerals (close to the hydrous calcium aluminosilicates tobermorite and crestmoreite) quickly begin to grow. These needles interpenetrate one another and bond tightly to sound, clean aggregate. An excellent review of the crystallization and solidification of cement was given by Double and Hellawell (1975). The reaction rate of the setting can be slowed by various additives before and after calcining (including gypsum powder after calcining) so that setting time, early strength, and heat generation can be controlled.

The quarried cement rock that becomes the kiln feed must be compositionally within the Portland cement zone of the ternary diagram, and the kiln feed must be as homogeneous as possible to ensure that every bag of the product will test out properly. Thus, a good quarry (like the one that supplies the Rillito plant) takes rock from different parts of the Paleozoic section and blends them at the crusher dump. Also, naturally occurring impure limestone formations may be quarried, such as the Horquilla or Earp, that are composed of limestone, some clays, and some silica so that the calcined product falls in the Portland cement compositional zone.

Sampling and XRF analysis start in drill holes and blast holes in the quarry, and continue throughout the process. Blending and mixing occur at several points (some of them spectacular, as at the stacker-reclaimer house, the largest single room in Arizona). Then, just before it enters the 1400°C kiln, pure limestone (for CaO), Pantano clay that we will see this afternoon (for Al_2O_3), silica sand (for SiO_2), and/or hematite or magnetite from a variety of sources (for Fe_2O_3) can be added in carefully controlled and monitored amounts.

This plant is one of two in Arizona, the other having been sited at Cottonwood at a source of excellent cement rock and other additives from the Mogollon Rim Paleozoic exposures. This second plant serves the north Phoenix-Flagstaff area, and also supplied cement for (and was amortized by) the Glen Canyon Dam. (J.M.G.)

We will tour the quarry and plant for about two hours, departing southward at 10:30.

Return to east-bound (south) I-10. (1.5)

19.0 Go south on I-10 to Orange Grove Road, Exit 250. (6.8)

Now that you're knowledgeable about cement, you will appreciate that 65 per cent of concrete by volume is actually an inert filler termed aggregate. The cheapest source of that filler in the Basin and Range province is river alluvium. As we head south toward the Tanner facility, notice that northwest Tucson construction expansion (even in these hard times) has justified the existence of several sand and gravel operations in the Santa Cruz River floodplain. (J.M.G.)

21.9 Stewart Block plant on west side of I-10. At this plant, various aggregates, including light-weight ones, are mixed for cinder blocks. The cement-aggregate mix is intruded into molds, compressed, extruded, and then cured for several days in 100 percent relative humidity ovens. All sorts of additives generate different weights, colors, and surface textures. Vibrating the blocks after they are extruded out of their molds produces slump block with outward-bowed slumped sidewalls. (J.M.G.)

23.1 Near Cortaro Road, there is another sand and gravel operation with characteristic concrete batch-plant superstructures.

24.6 Sunward Materials, just north of Ina Road, sells all grades of aggregate, sand, and gravel to the general market for fill, ballast, and road metal. They are also suppliers to Industrial Asphalt (a batch mixing plant for asphalt concrete and asphalt road surfacing) on the south side of their property. (J.M.G.)

25.8 Turn right on Orange Grove Road, then right on north-bound frontage road, then left at entrance to Tanner Rock and Sand Company. Park in parking lot near gate. (0.6)

Stop 2 Tanner Rock and Sand Company

Host, Ron Greene, will meet us. We will spend about 4 minutes with him, departing at 11:30, so please assemble quickly at the various points to see the quarry, mining, hauling, screening, and washing facility. There is no handout.

As many of you know, there are strict geologic guidelines for defining satisfactory aggregate deposits. Poor sorting in the deposit resulting in a range in grain sizes from cobbles to sand is desirable. The particles must be sound, tough, and durable, free of reactive alkalies, caliche coatings, organic debris, and trash, and the whole must be unindurated. Exploration techniques range from geomorphic-geologic terrane analysis, to geophysics, and finally to auger drilling. More will be said of all this on site. Several reference articles on properties and exploration methods, and a bibliography are available from John M. Guilbert. (J.M.G.)

Return to east-bound (south) I-10. (0.4)

26.8 Go south on I-10 to 22nd St., Exit 259. (8.9)

28.3 To the southwest at about 2:00 from your vehicle, the white batch plant tower and the four or five cranes mark Tanner's pre-stressed concrete forming and pouring yard. Here they stretch steel wires through forms to make pre-stressed concrete beams, pillars, posts, columns, roof panels, tilt-up slabs and other similar products. The concrete poured around the wires becomes internally stressed like tempered glass when the forms are stripped and the stretched wires are released at their ends. The sometimes intricately shaped structural components are then trucked to the construction site. (J.M.G.)

33.7 Near the Speedway exit there is a good view to the southwest (2:00) of the quarry on A Mountain (Sentinel Peak) that provided much of the dark brown, gray, and black basaltic andesite that early-days Tucson was made of, including the University of Arizona perimeter walls. (J.M.G.)

35.7 Take Exit 259 and turn right (west) onto 22nd St. then right onto Mission Road access. (1.0)

36.7 Turn left onto Mission Road at the T-intersection. (0.4)

37.1 Turn left into parking lot of Pima County Department of Transportation and Flood Control District (1313 S. Mission Rd.) Walk through the corridor past the information office door to an interior patio opposite a red building.

Stop 3 Pima County Materials Testing Laboratory

Pima County maintains an extensive testing laboratory at this facility. Lab Chief John Norton is our host. (The Arizona Department of Transportation maintains a separate laboratory at. 22nd St. and S. 7th Ave.)

A vital part of highway construction and both public and private building construction is quality control--the assurance that concrete (the product of mixing cement and aggregate) meets specifications. Avoidable disasters such as the Chicago hotel causeway failure that took threescore lives a few years ago remind us of the importance of quality control.

As you will see, the testing procedures are run on cored samples as well as on samples poured at the same time as bridge abutments or road surfaces, on the job. The poured samples must be cured under controlled conditions in the lab and tested at various times to assess final strength. The elaborate physical, chemical, and mechanical tests and testing procedures that check the combined products of our two earlier stops are the subjects of this third stop. (J.M.G.)

The next stop is for lunch at Sentinel Peak Park. Return to Mission Road and turn right. (1.3)

38.4 Intersection of Mission Road and Congress St. Turn left on Congress St. (0.3)

38.7 Intersection of Congress St. and Cuesta Ave. Turn left on Cuesta Ave. Cuesta Ave. becomes Sentinel Peak Road at bottom of hill. (1.9)

40.6 Parking lot at top of Sentinel Peak.

LUNCH STOP. No glass containers are allowed in Sentinel Peak Park.

After lunch, return to east-bound (south) I-10 via Sentinel Peak Road, Cuesta Ave, and Congress St. (2.0)

Day 1 - Afternoon

Marble Quarries, Santa Rita Mountains - Ted H. Eyde.

Pantano Clay Quarry and Rock-Avalanche Deposit, Cienega Gap - Ted H. Eyde and Brenda B. Houser.

42.6 Intersection of I-10 and Congress St. Go south (east-bound) on I-10 to I-19. (1.8)

44.4 Intersection I-10 and I-19. Take I-19. (6.4)

50.8 Martinez Hill on the east side of I-19 is composed of interbedded mid-Tertiary basaltic andesite flows and volcaniclastic conglomerate. A flow near the top of the hill yielded a K-Ar age of 24.7 Ma (Percious, 1968). (2.4)

53.2 Tailings of the open pit porphyry copper mines of the Pima mining district are from 12:30 to 2:30. The broad, low range behind the tailings to the south-southwest is the Sierrita Mountains. The Sierritas are the site of important copper deposits associated with Laramide intrusive bodies. The mineralization occurs as copper-bearing skarns in Paleozoic carbonate rocks, as sulfide veins in igneous rocks, and as porphyry copper deposits, all associated with quartz monzonite stocks.

In addition to minor exposures of Precambrian granitic rocks and Paleozoic sedimentary rocks, the Sierritas consist chiefly of Jurassic intrusive rocks, Laramide intrusive and volcanic rocks, and mid-Tertiary volcanic and sedimentary rocks. The Laramide age rocks, Red Boy Rhyolite and Ruby Star Granodiorite, have been interpreted by Lipman and Fridrich (1990) to be the ash-flow caldera fill and sub-caldera pluton of a cretaceous caldera. The Sierrita Mountains have been mapped by Cooper (1973) and Drewes and Cooper (1973). (7.6)

60.8 Intersection I-19 and Helmet Peak Road, Exit 75. Go left (east) on Sahuarita Road toward Sahuarita. (1.8)

62.6 Santa Cruz River. (1.2)

63.8 Intersection of Sahuarita Road and Santa Rita Road. Turn right (south) on Santa Rita Road. (2.9)

66.7 Junction of Santa Rita Road and Country Club Road; continue southeast on Santa Rita Road. (1.4)

Mount Wrightson, the highest peak in the Santa Ritas at about 2:00, is underlain by Triassic rhyolitic and latitic volcanics and lies in the central structural unit of the Santa Ritas. It is separated from the northern structural unit by the northwest-trending left-lateral(?) Sawmill Canyon fault zone that crosses the range just northeast of Mount Wrightson (Drewes, 1971a, 1972).

The northern Santa Rita Mountains are directly ahead of us and to the left (fig. 2). The white scar at about 11:00 is the Pfizer marble quarry. South of the quarry, the northern Santa Ritas consist chiefly of 1.4 Ga Precambrian Continental Granodiorite, overlain on the east flank of the range by Paleozoic sedimentary rocks and the

Figure 2.--Geologic map of the northern Santa Rita Mountains from Drewes (1980). Field trip stops are shown by red dots; Stop 4 (Pfizer quarry) is on the south, Stop 5 (Georgia Marble quarry) is on the north. Scale is 1:125,000. Contour interval is 200 ft. For explanation of map units and symbols, see Drewes (1980). The unit labeled Tg (54 and 56 Ma)is the Laramide intrusive responsible for marblization of the Escabrosa Limestone at the Pfizer quarry. At the Georgia Marble quarry, the Escabrosa was marblized by the Laramide intrusive body labeled Klq (74 Ma).

Lower Cretaceous Bisbee Group. North and east of the quarry, the range is structurally lower. There are a few exposures of Continental Granodiorite along the western edge of the range overlain by a band of Paleozoic sedimentary rocks, but most of this part of the range consists of Bisbee Group rocks overlain by late Cretaceous volcanics on the east (Drewes, 1971b, 1972, 1980).

The Precambrian and Paleozoic rocks along the western and northern edges of the northern structural unit of the Santa Rita Mountains were intruded by numerous 54 to 56 Ma granodiorite to quartz monzonite stocks and dikes (Drewes, 1971b). Contact metamorphism of the Mississippian Escabrosa Limestone by these intrusions resulted in the marble that is mined at both the Pfizer quarry and the Georgia Marble quarry to the north.

68.1	Enter Santa Rita Experimental Range. (5.9)
74.0	Huerfano Butte, a small granodiorite or quartz monzonite stock with a central aplite dike (Drewes, 1971b). (1.5)
75.5	Junction of FS 505 (Helvetia) and FS 485 (Box Canyon). Go left on 505. (1.1)
76.6	Junction of FS 505 and FS 170. Go left on 170. (2.7)
79.3	Pfizer marble quarry parking lot.

Stop 4 Pfizer Specialty Minerals Marble Quarry

The development and production history of this quarry is given in Eyde and Eyde (this volume). Figure 2 shows the geology of the Santa Rita Mountains around the quarry site. There is virtually no information available on any aspect of the marble in this quarry (or the Georgia Marble quarry at the next stop) other than it is contact metamorphosed Mississippian Escabrosa Limestone. This is commonly the state of information regarding many industrial commodities. They are bulk sampled and bulk tested for marketable properties by industry and consultants, and the data are seldom published. Furthermore, some of the industrial mineral deposits have not been perceived as being as scientifically interesting as metallic mineral deposits, for example, so there has been less basic research done on them.

	Return to junction of Santa Rita Road and Country Club Road. (12.6)
91.9	Turn right (north) on Country Club Road to Sahuarita Road. (2.4)
94.3	Intersection of Country Club Road and Sahuarita Road. Turn right (east) on Sahuarita Road. (9.4)
103.7	Intersection of Sahuarita Road and

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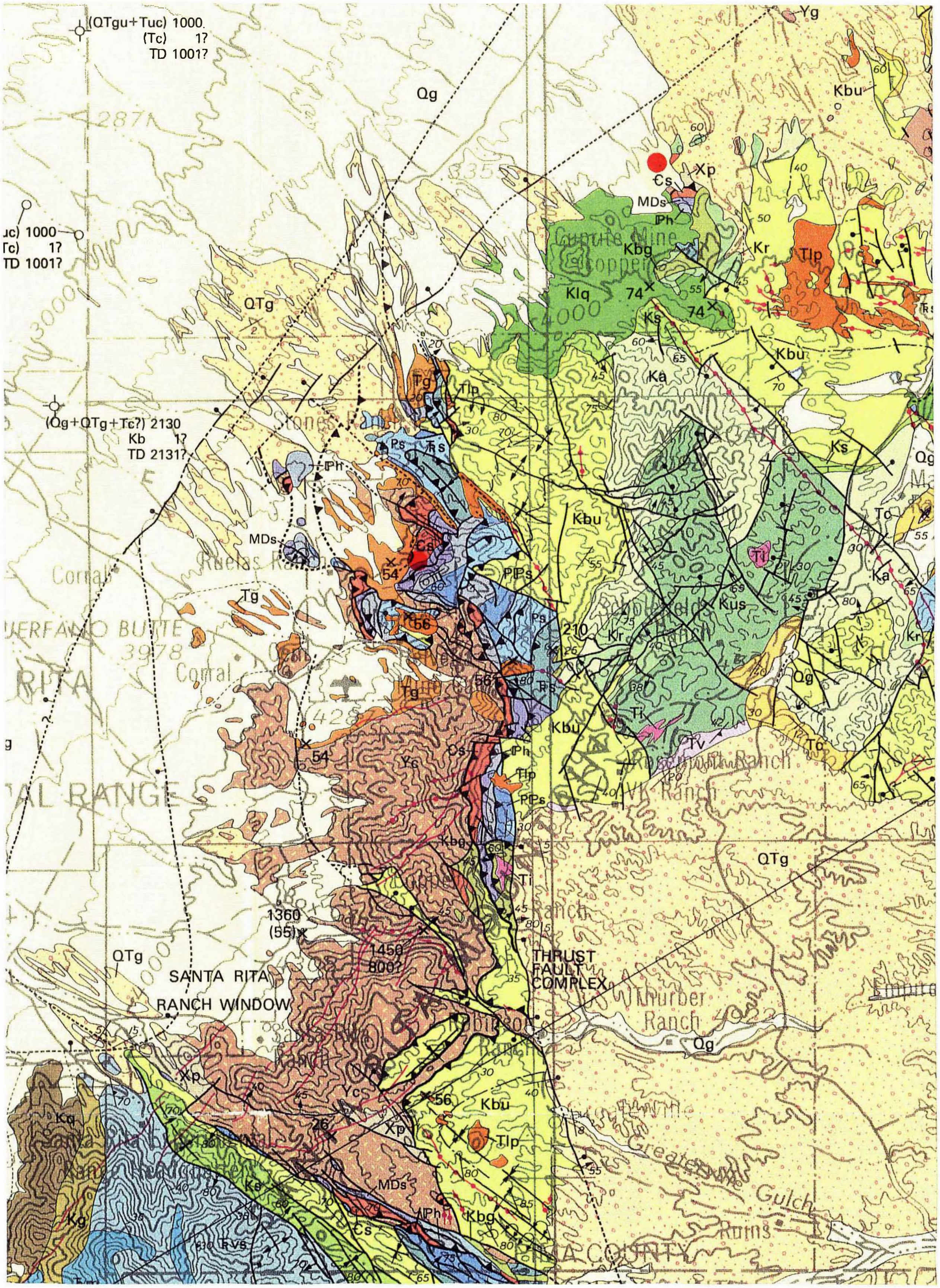
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COMPLEX
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RANCH WINDOW
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Ks
Cs
MDs
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Tlp
Kbg
Stones Ranch
Ruelas Ranch
Corral
HUERFANO BUTTE
3978
RITA
AL RANGE
Cuprite Mine
Rosemont Ranch
VK Ranch
Robinson Ranch
Thurber Ranch
Greaterville
Gulch
Ruins
PIMA COUNTY

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Houghton Road; continue (east) on Sahuarita Road. (3.0)

106.7 Intersection of Sahuarita Road and Wentworth Road. Turn right (south) on unnamed graded road. (1.1)

107.8 Parking lot at Georgia Marble Company quarry.

Stop 5 Georgia Marble Company Quarry

The development and production history of this quarry is given in Eyde and Eyde (this volume). The geology of the quarry and surrounding area is shown in figure 2.

108.9 Return to intersection of Sahuarita Road and Wentworth road. Turn right (east) on Sahuarita Road. (2.9)

111.8 Intersection of Sahuarita Road and Az. Rt. 83. Turn left (north) on Rt. 83. (3.1)

114.9 Junction of Rt. 83 and east-bound I-10 entrance ramp. Turn right onto I-10. (2.8)

117.7 Davidson Canyon. The middle conglomerate member of the late Oligocene to early Miocene Pantano Formation (Balcer, 1984) is exposed in roadcuts along I-10 east of Davidson Canyon. The Pantano is moderately well indurated and, here in the Cienega Gap area, dips chiefly to the east within a complex pattern of fault blocks. It is overlain with angular unconformity by Neogene sediments that have not been studied in this area. (0.6)

118.3 Porphyritic andesite member of the Pantano Formation overlying the middle conglomerate member. The andesite is about 20 m thick here and appears to be propylitically altered. K-Ar whole-rock age is 24.9 Ma (Dickinson and Shafiqullah, 1989). Lower Cretaceous Bisbee Group rocks are exposed in a fault block for about a mile east of the andesite. (2.0)

120.3 Cross Hill clay quarry at 10:00. (2.5)

122.8 Leave I-10 at Marsh Station Road, Exit 289. Exit Ramp crosses back over I-10; turn left (west) at the "T" intersection. (1.8)

124.6 A large landslide or rock-avalanche has been recognized overlying the Pantano Formation in Cienega Gap (Drewes, 1977; Balcer, 1984; Yarnold and Lombard, 1989). An enigmatic structure exposed in the cuts on either side of the road (fig. 3A) consists of chaotically disrupted sequences of the mudstone member of the Pantano Formation, separated by a 12-m-wide septa of rock-avalanche breccia. A block of Bolsa Quartzite (part of the breccia) on the south side of the road is about 6 m across. This exposure may represent juxtaposed deformed slivers of Pantano mudstone and rock-avalanche breccia near the base or side of the avalanche deposit. (0.4)

125.0 Turn right on dirt road, drive about 0.1 mi to the clay pit at the base of what is left of Cross Hill, and park.

Stop 6A Pantano Clay Quarry at Cross Hill

The high-alumina clay mined in Cienega Gap southeast of Tucson occurs near the top of the Pantano Formation of late Oligocene and early Miocene age. The clay is used for making bricks and also as a source of alumina in cement production at the Arizona Portland Cement Company's Rillito plant.

The clay beds range in color from light- to dark-reddish-brown and contain veins of

Figure 3.--Photographs of the rock-avalanche deposit and underlying mudstone member of the Pantano Formation, at Cross Hill in the Cienega Gap area. (A) Lens of avalanche breccia separating highly deformed sequences of Pantano mudstone. (B) View of Cross Hill, looking northeast at Stop 6A, showing the contact of the rock-avalanche deposit with the Pantano mudstone. The saguaro at the upper left is about 3 m high. (C) View of the Cross Hill clay quarry looking southeast.

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satin spar, a fibrous variety of gypsum, that are 1 cm to several centimeters thick. Pantano clays have the following characteristics that make them suitable for making bricks:

> Good plasticity, good colors, and good strength.
> They fire within 100° C of each other.
> They exhibit a short, abrupt vitrification range.
> They show only small variations in generally low calcium carbonate content.

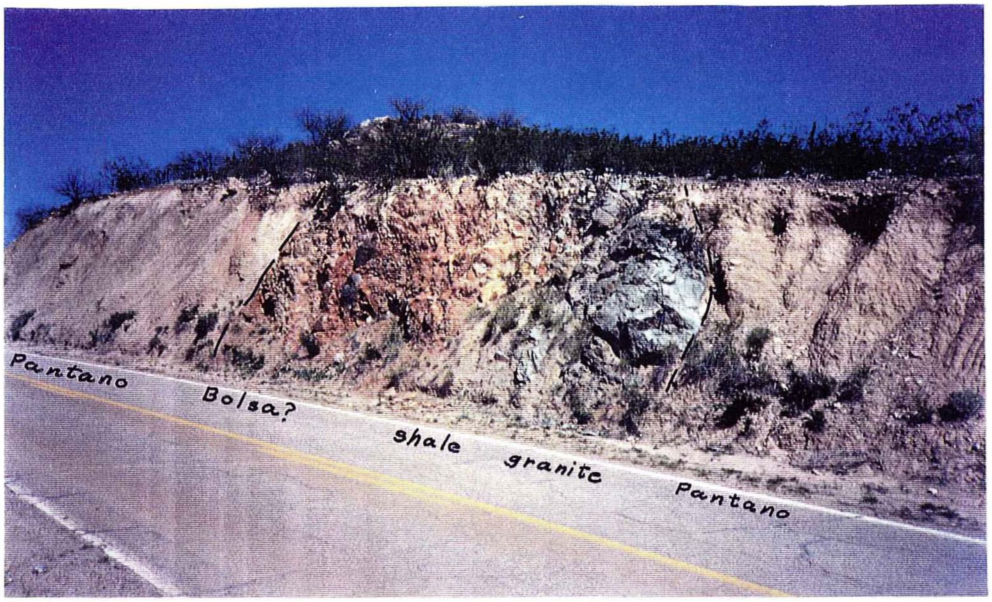
Experience has shown that blending various clays from the Pantano area produces bricks that exhibit a wide range of colors after firing. At the Phoenix Brick yard, the Pantano clays are further blended with grog (crushed bricks) and clays from Tolleson, southwest of Phoenix, to produce a satisfactory quality brick. The Tolleson clays have low plasticity and, thus, are hard to extrude, but are needed to control shrinkage and extend the vitrification range. In addition, blending in the locally mined Tolleson clay significantly reduces manufacturing costs.

The Pantano clay is the only source of low-alkali, high-alumina clay within a cost effective hauling distance from the Arizona Portland Cement Company's Rillito plant. Table 1 is a comparison of the alumina and alkali content of clays from other deposits in Arizona with the Pantano clay. Clearly, the Pantano clay is an uncommon clay with properties that differentiate it from other clays in Arizona. (T.H.E., D.T.E)

The clay quarry here at Cross Hill provides an excellent exposure of the base of a large rock-avalanche deposit (figs. 3B and 3C). The deposit was noted and mapped by Drewes (1977) and Balcer (1984) and its characteristic facies were described in relation to other large rock-avalanche deposits in the southwest by Yarnold and Lombard (1989). The lithologies present in the deposit are Precambrian Rincon Valley Granodiorite (Drewes, 1977), Paleozoic sedimentary rocks (Bolsa Quartzite, Abrigo and Martin Formations), and diabase(?). It overlies the Pantano Formation (chiefly the mudstone member) in angular unconformity and is overlain by gravely conglomerate of probable late Miocene and Pliocene age (Drewes, 1977). The deposit is about 35 m thick at Cross Hill, but could be as thick as 70 m about 2.5 km to the north. Yarnold and Lombard (1989) calculated that the deposit crops out over an area of more than 6 km^2 and is more than 4.5 km long. They thought that the avalanche was apparently derived from the north or northeast perhaps during tectonic denudation of the Catalina core complex.

Figure 3B shows two or three lenses of the avalanche deposit at Cross Hill. There is a thin zone of deformation in the Pantano mudstone at the base of the deposit. The basal unit of the avalanche deposit on the west (left) side of Cross Hill is a lens of comminuted, altered limestone about 5 to 10 m thick (fig. 3B); this lens is overlain by altered brecciated granodiorite on the west and brecciated Bolsa Quartzite on the east. The nature of the contact between the granodiorite and Bolsa Quartzite is gradational and obscure.

123.3 Return to Pantano Road and turn right (west). (1.9)


Pantano
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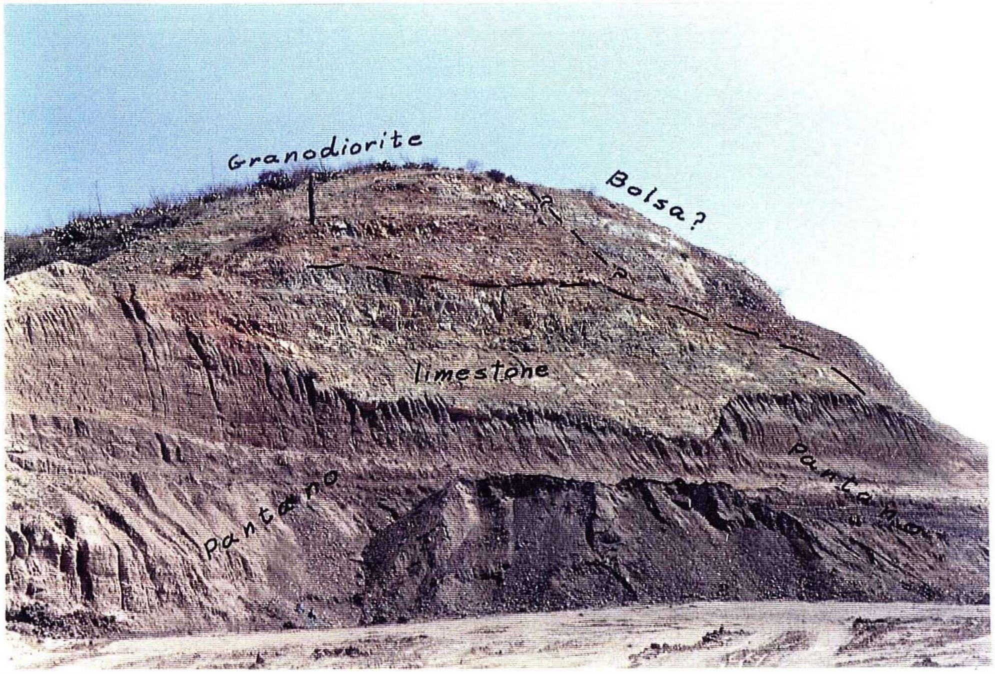
Granodiorite
Bolsa?
limestone
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Pantano

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Table 1. Chemical analyses of Arizona clays

	ARIZONA CLAY SAMPLES						
SAMPLE LOCATION	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	Total K_2O	Alkalies[1]	S/R[2]
COCHISE COUNTY							
Benson Area	-	-	-	1.22	3.20	3.30	
GILA COUNTY							
Pine Area	68.88	12.90	4.60	-	1.65	N/A	3.94
MARICOPA COUNTY							
Cave Creek Area	-	-	-	1.44	3.64	2.41	
Fort McDowell Area	-	-	-	1.04	3.02	3.03	
Horseshoe Dam Area	-	-	-	3.44	3.78	5.93	
McDowell Mtns. Area	-	-	-	1.64	2.64	3.38	
Morristown Area	72.98	17.97	1.21	0.07	0.21	0.21	3.81
MOHAVE COUNTY							
Needles Area	74.72	14.76	0.32	0.30	0.12	0.20	4.95
PIMA COUNTY							
Arivaca Area	-	-	-	1.53	2.97	3.49	
Pantano Area	45.80	12.85	3.60	0.81	3.06	2.82	2.78
Az. Portland Cement Co. Clay Deposit	48.87	16.13	4.38	0.26	3.38	2.48	2.38
Tucson Area	52.58	13.31	3.34	0.84	3.46	3.12	2.68
Rillito Area	61.33	15.00	5.00	1.67	3.47	3.95	3.07
Waterman Mtns. Area	-	-	-	0.20	4.40	3.10	
PINAL COUNTY							
Goldfield Area	59.63	15.80	4.99	2.30	5.20	5.72	2.87
Superior Area	76.98	11.23	4.59	1.84	1.46	2.80	4.87
YAVAPAI COUNTY							
Paulden Area	60.56	7.67	2.83	0.23	1.89	1.47	5.77
Wickenburg Area	66.95	13.30	1.75	1.28	2.69	3.05	4.45
YUMA COUNTY							
Kintor Area	-	-	-	1.75	2.89	3.65	
Welton Area	54.45	17.82	5.48	1.48	2.63	3.21	2.34

Total Akalies[1] = $Na_20 + (K_20 \times .658)$

S/R Ratio[2] = $\dfrac{\%\ SiO_2}{\%\ Al_2O_3 + \%\ Fe_2O_3}$

125.2	Intersection of Pantano Road and graded road. Turn right on graded road. (0.4)
125.6	Intersection of graded road and graded road along north side of railroad track. Turn right and drive along north side of track. (0.5)

Stop 6B Contact of Rock-Avalanche Deposit with Underlying Pantano Mudstone Member

Yarnold and Lombard (1989) describe this exposure of the rock-avalanche deposit as follows:

> In what appears to be the medial portion of the deposit, a railroad cut 3 km northwest of Cross Hill exposes the base of the avalanche lobe. Here the landslide debris overlies a debris-flow conglomerate up to 5 m thick that contains numerous lithologies not present in the avalanche breccia. The debris-flow deposit in turn overlies thin-bedded and well-sorted sandstone and mudstone. The basal contact of the avalanche deposit at this locality is undulatory with up to a few meters of relief, and displays a zone of comminution 5 to 10 cm thick that contains silt- to pebble-sized clasts derived from Rincon Valley Granodiorite. The overlying rock-avalanche breccia is nearly matrix-free, except in its lowermost 2 m where a thin "stockwork" of reddish silt and arkosic sand outlines fractures. A clastic dike, approximately 1 m long and 5 cm thick near its base, intrudes the avalanche debris in this exposure and is composed of crushed granodiorite as well as material derived from the sandstone and mudstone substrate exposed in the immediate vicinity.

End of Day 1 of field trip. Return to Tucson by way of Pantano Road and west-bound I-10.

San Pedro Valley

Day 2 - Morning

White Cliffs Diatomite Deposit - Jonathan D. Shenk

Mileage	Comments
0.0	U of A red permit parking lot at the southeastern corner of Euclid and E. 4th St. Go north on Euclid (becomes 1st Ave.) to Grant. (1.4)
1.4	Junction of 1st Ave. and Grant. Go west on Grant to Oracle Road. (0.9)
2.3	Junction of Grant and Oracle Road. Go north on Oracle Road (Az. Rt. 89) to Oracle Junction. (22.3)
24.6	Intersection of Az. Rts. 89 and 77 at Oracle Junction. Bear right on Rt. 77 to Mammoth. (17.4)
42.0	Junction of Rt. 77 and Old Rt.77 at the south edge of Mammoth. Turn right on Old Rt. 77. (0.7)
42.7	Junction of Old Rt. 77 and Bluebird St. across from the Blue Front Bar. Turn right on Bluebird St. Clark Sand and Gravel operation on right. Cross San Pedro River at ford. Bluebird St. becomes Copper Creek Road (0.8)
43.5	Junction of Copper Creek Road and a paved road on east side of San Pedro River. Turn right (south) on paved road. (0.8)
44.3	Gypsiferous mudstone on left with interbedded 1-ft thick air-fall tuff bed. (2.5)
46.8	Pavement ends. San Manuel tailings ponds and smelter on west side of San Pedro River. (3.6)

50.4 Gust James Wash; north end of White Cliffs property. (0.4)

50.8 Entrance to inactive White Cliffs mine on left. (0.9)

51.7 Adit Canyon on left; well on right. (1.3)

53.0 Turn left on dirt road (Rhodes Ranch Road). (0.9)

53.9 Turn right on little-traveled dirt road. Go about 0.2 mi and park.

Stop 7A Camel Canyon Overlook

Camel Canyon, informally names by University of Arizona paleontologists for the abundant fossilized camel bones found here, is the southern limit of the White Cliffs diatomite deposit (fig. 4). The diatomaceous sediments exposed in Camel Canyon are mapped as part of the White Cliffs member (Shenk, this volume) using the following field evidence: (1) the occurrence of diatomite, (2) the extensive chert development, and (3) the bright white color. Exact correlations with specific horizons in the White Cliffs member, however, are uncertain because the upper ash and lower ash

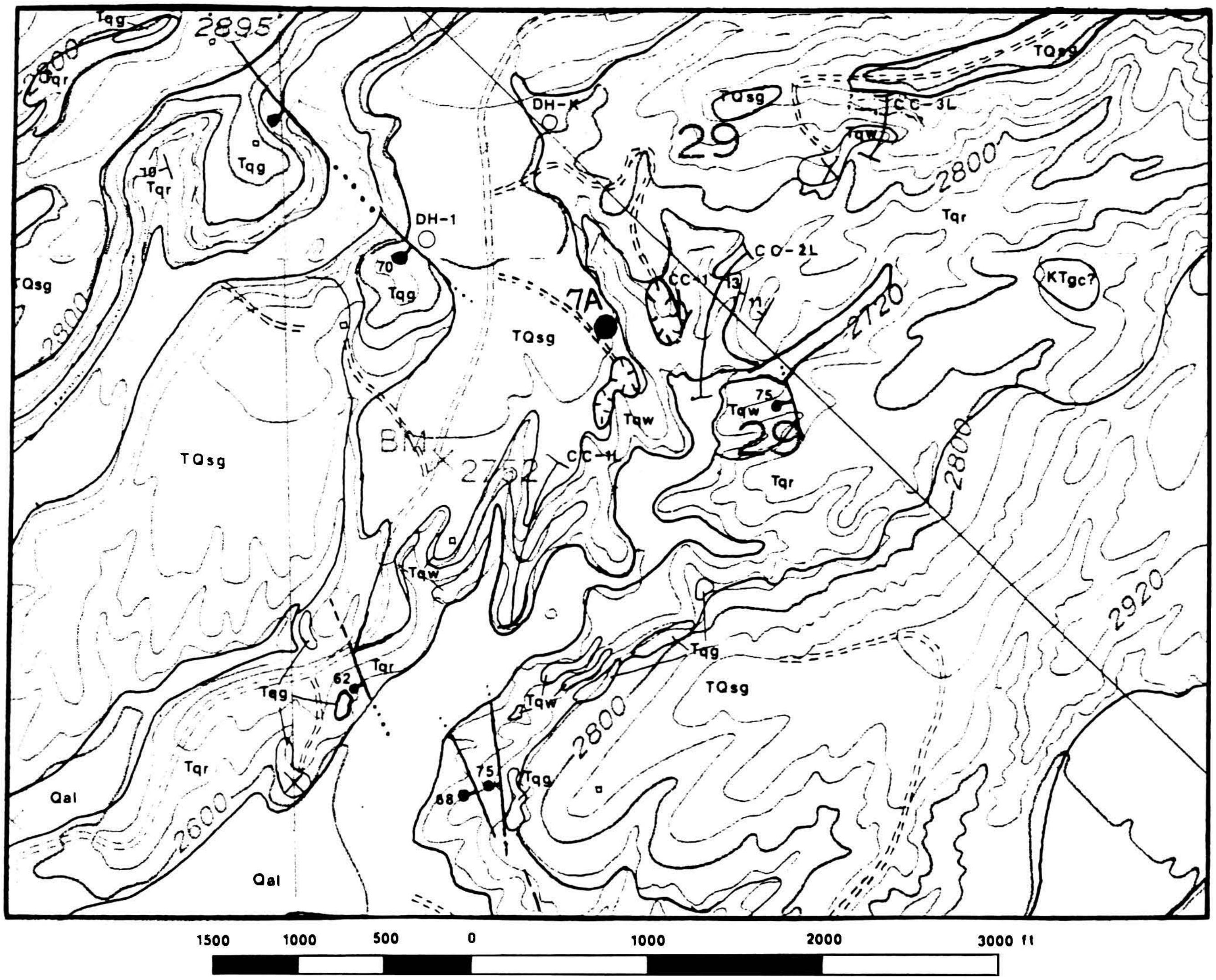


Figure 4.--Geologic map of section 29 of the White Cliffs diatomite deposit showing field trip Stop 7A (from Shenk, 1990).

marker beds are not readily identifiable. A small outcrop of granitic bedrock is exposed approximately due east from the quarries. Adjacent to the bedrock outcrop, thin beds of granitic detritus containing abundant shattered vertebrate fossils interfinger with the surrounding silt. This granitic outcrop is thought to be part of a regional buried bedrock high that limited the deposition of diatomite to the south.

Armand Bollaert first defined the diatomite resource in Camel Canyon in 1952 during an exploration program for Spencer Chemical Company. The actual quarries were probably not developed until the late 1960s or early 1970s, and additional minable material appears limited. However, an exploration hole drilled in 1957 about 300 m west of the quarries encountered more than 43 m of interbedded diatomite and chert, indicating that the potential for minable diatomite improves to the north. (J.D.S.)

Return to road along east side of San Pedro River. (1.1)

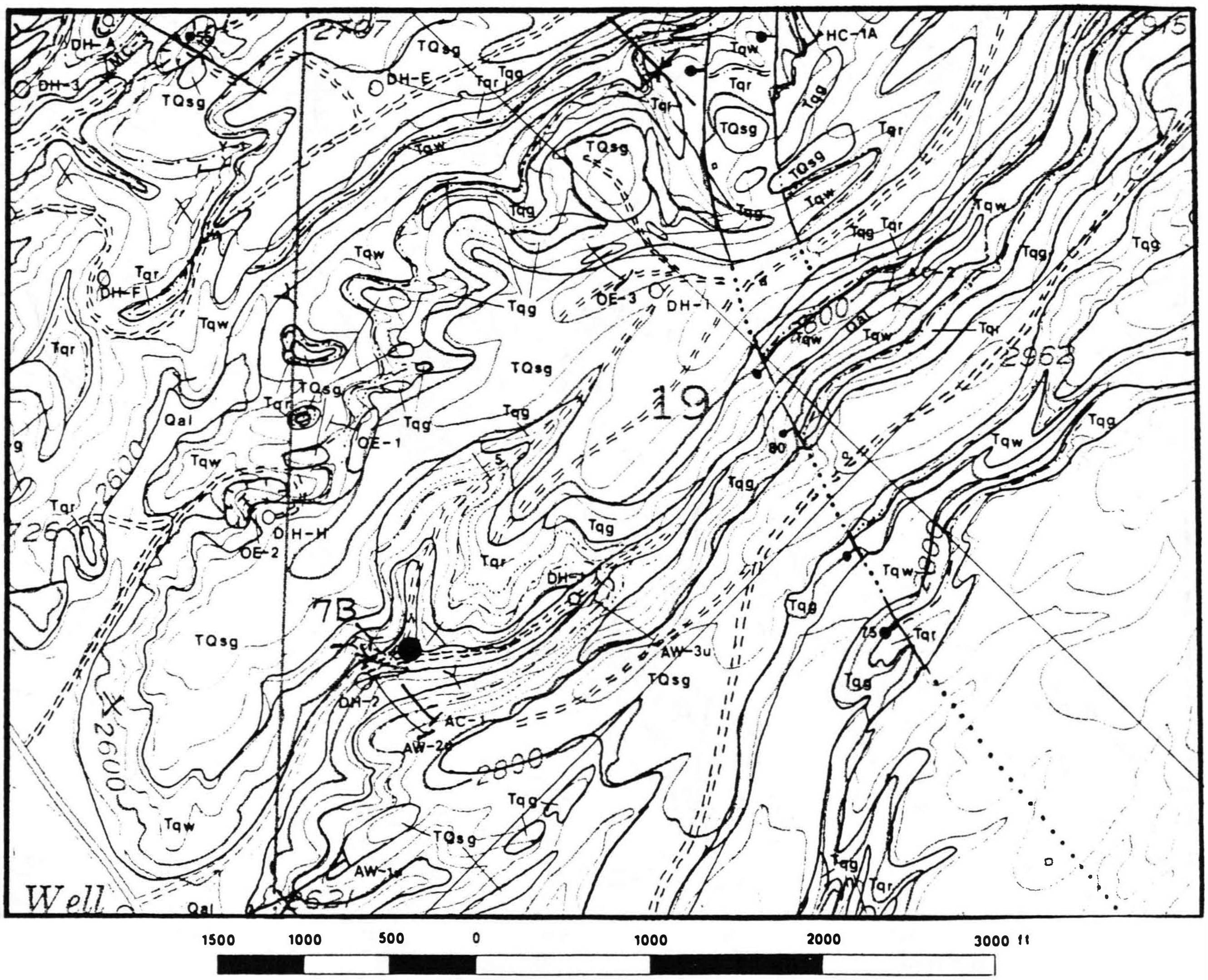


Figure 5.--Geologic map of section 19 of the White Cliffs diatomite deposit showing field trip Stop 7B (from Shenk, 1990).

55.1 Turn right (north) on road along river and drive to mouth of Adit Canyon. (1.3)

56.4 Turn right, drive up Adit Canyon 0.4 mi, and park at the fork in the road.

Stop 7B Adit Canyon

Adit Canyon (fig. 5) was informally named for the small adits located near the mouth of the canyon on the northwest wall. Diatomite was quarried here perhaps as early as the 1920s and probably again in the 1940s. At this stop, we will park the vehicles near the old workings and hike back the canyon about 1 km to examine the thickest exposed section of diatomite on the property.

At the mouth of the canyon, the relationship between the stratigraphically lower White Cliffs member, the middle silt, and the stratigraphically higher Gust James member is nicely exposed (Shenk, this volume). The lower ledge-forming bed is the upper volcanic ash marker bed, and the resistant bed 9 m higher in the section is a poorly sorted, locally crossbedded, gravelly sandstone. As we journey back the canyon we will be walking up section because of the slight 3° NE dip of the beds. Approximately 0.4 km from the adits we will pass an exposure of the upper ash marker bed next to the road. Approximately 0.8 km from the adits, near the overhead powerlines, we will pass a high-angle normal fault. The displacement is down to the west, which exposes the White Cliffs member on the eastern upthrown block. Note the development of thick chert beds in the White Cliffs member. In the center of the NE1/4 of section 19, the canyon walls are readily accessible and the section can be examined. The highest quality beds are found at the base of the section. (J.D.S.)

Lunch Stop. We will eat lunch here in Adit Canyon after we return from the hike up the canyon.

After lunch, return to river road and drive 7 north to intersection of river road and Copper Creek road east of Mammoth. (8.6)

Day 2 - Afternoon

Gold Bond Gypsum Quarry - Dennis Mackovjak
Asbestos Occurrence and Troy Quartzite Quarry - John M. Guilbert
Kalamazoo Landscaping Materials Deposit - Robert L. Hockett

65.0 Junction of river road and Copper Creek Road. Continue straight ahead on river road. (2.3)

67.3 Junction of river road and Rt. 77. Go right (north) on Rt. 77. (9.9)

77.2 Turn right on road to Gold Bond gypsum quarry (mileages may be imprecise). (1.7)

78.9 Park at quarry.

Stop 8 Gold Bond Gypsum Quarry

Gold Bond Building Products, a division of National Gypsum, quarries gypsum from the Aravaipa Creek deposits for the manufacturing of wallboard in their Phoenix plant. Guiding the tour will be Dennis Mackovjak, Gold Bond geologist and quarry superintendent.

Return to Rt. 77. (1.7)

80.6 Turn left (south) on Rt. 77. (2.2)

82.8 Junction of Rt. 77 and Aravaipa Road. Turn left (west) opposite Aravaipa Road. Bear left at 0.15 miles; ford the San Pedro River at 0.6 miles; bear left at the Y (we will take the right fork here later to see the silica flux quarry). At 1.15 mi there is a fork in the broad sandy Putnam Wash. To save opening and closing a gate, stay LEFT, cross the wash, climb the 4-foot bank, cross the cattleguard, and bear right. Follow the fence to the Putnam Trestle (at 1.35 miles). The asbestos-bearing outcrops of Mescal

Figure 6.--Geologic map of Putnam Wash area (Krieger, 1968) showing Stop 9 on the south side of the wash and Stop 10 on the north side. Scale, 1:24,000; contour interval, 40 ft. Explanation of map units and symbols given in Krieger (1968).

Limestone are 0.5 mi up the broad wash west of the trestle. (1.9)

84.7 Park at the Mescal Limestone outcrops.

Stop 9 Putnam Wash Asbestos Occurrence

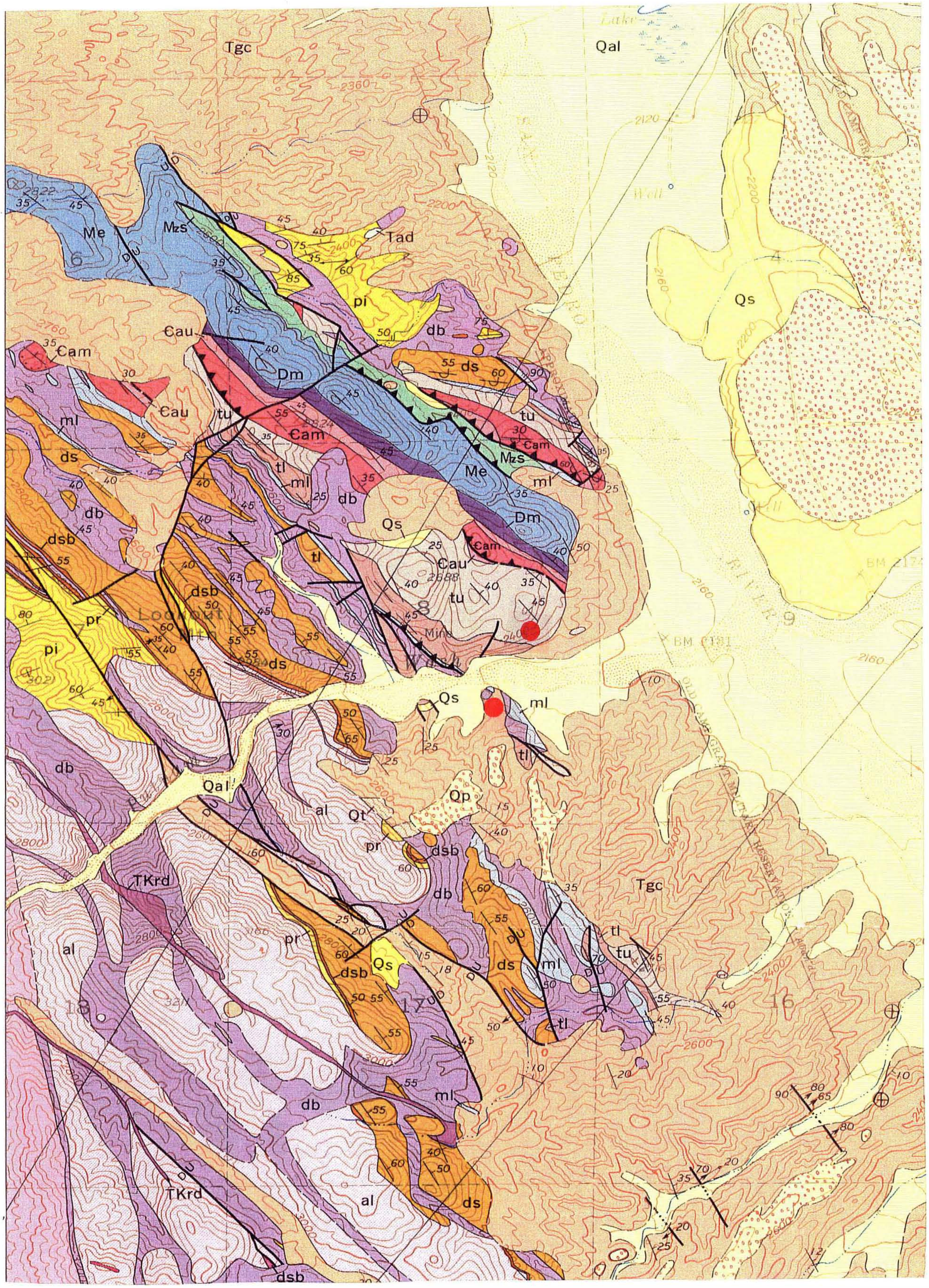
The asbestos occurrence here in Putnam Wash is a microcosm of the Salt River Canyon (SRC) asbestos deposits and has the advantage of being several hours closer to Tucson than the actual Regal Mine area at the SRC. The SRC and Putnam Wash deposits are unusual, being Type III asbestos occurrences (Ross, 1987), and result from serpentinization of limestone, important only in the Globe (SRC), Arizona, and Barberton, Republic of South Africa, areas. (Type I is in Alpine-type ultramafic rocks, including ophiolites; II is in layered ultramafic complexes; IV is in banded ironstones). The Globe deposits are world-class, having provided exceptionally long-fiber (up to 45 cm!), flexible, spinnable, low-iron (high thermal and electrical resistance) chrysotile.

The principal type of asbestos is the mineral chrysotile, a hydrous trioctahedral 1:1 layer magnesium silicate, $Mg_3Si_20_5$ $(OH)_4$. Morphologically, chrysotile is a rolled-up, tubular version of antigorite, the magnesium analog of dioctahedral kaolinite. Chrysotile generally occurs where hydration of olivine (Mg_2Si0_4) or enstatite ($MgSi0_3$) in ultramafic rocks has resulted in fluids that have the appropriate composition to form chrysotile. But here (and at SRC), the juxtaposition of chemical components comes from intrusion of Precambrian diabase into Apache Group Mescal Limestone. Magnesium (plus silica and some water?) from the diabase combined with magnesium and some silica and water in the dolomitic limestone in an environment of CO_2 flux (plus groundwater?) to produce abundant massive serpentine and common cross-fiber asbestiform chrysotile at the contacts of diabase with Mescal. The budget problems of where the chemical components really came from and what the temperature and pressure conditions were (400-500°C?) have not been resolved.

There are outcrops on both sides of the wash that are interesting and show much the same relationships. The contact of diabase with Mescal Limestone extends up along the ridge to the south as the map shows (fig. 6), and there are more occurrences there. Notice that roughly parallel to the contact are bands of apple-green serpentine, and that within and generally parallel to these bands are narrow veins of cross-fiber asbestos. Multiply this relationship by several orders of magnitude, increase the fiber length to 5 to 10 cm, and you've got SRC and the Regal Mine area.

Among the interesting observations is that most of the cross-fiber veins have no centerlines, which has provoked endless (and so far virtually fruitless) debate. How did the veinlets form? If they are replacements you would expect uneven, gradational walls, but the walls are sharp. If they are open-space fillings from a watery fluid, you would expect center lines and banding. If they are open-space fillings from a gel or colloid (to avoid the need for centerlines), you have to invoke a dilational environment...and where did the gel come from? Some investigators have suggested that fibers growing at their ends pushed the walls apart; another proposed that tectonic forces opened the cracks with chrysotile migrating into them instantly to occupy the voids.

Guilbert has opined that a mildly tensional dilational Environment might simply permit recrystallization of massive serpentine to chrysotile (perhaps just as an inversion with falling temperature) without mass movement, in which case the veinlet walls are just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recrystallization boundaries. But why are they so sharp and regular? Whatever your model, the chrysotile appears to be texturally late and in dilational openings, not what you'd expect along an intrusive contact. Was space created by driving off fugitive CO_2 at the Mescal-diabase contact? There are local calcite and quartz veinlets, as you'll note.

The following excerpt from Bates (1969) is pertinent to this problem:

> The Arizona chrysotile is one of the few deposits known in which the enclosing serpentine was not derived from an ultrabasic rock, but from a limestone. The Mescal Limestone (Precambrian) has been extensively intruded by sills of diabase, which provided solutions that have serpentinized certain beds of limestone. Chrysotile occurs as cross-fiber veins that parallel the bedding. In discussing its origin, Bateman (1923, p.677-680) pointed out that some of the veins are lenticular, but that neither the upper nor the lower surface of the enclosing serpentine layer shows any outward bulge opposite the chrysotile lenses. He therefore concludes that, in forming, the cross-fiber did not push apart the walls. Open-fissure filling is also unlikely, as the weight of overlying strata would keep any horizontal fissures closed. Bateman believed the chrysotile must have grown by replacement of the serpentine above and below. A slight change in the composition, pressure, or temperature of the hydrothermal solutions coming from the diabase may have made the serpentine phase unstable and chrysotile the stable form. A similar explanation -- involving neither tension, net expansion of the rock volume, nor open fissures -- may yet be forthcoming for chrysotoile veinlets in massive serpentine of the Quebec type. Although occurrence is erratic, and production has never been large, the Arizona chrysotile has exceptional fiber length and low iron content, and is a high-grade spinning fiber.

Note the bleaching associated with serpentinization. Across the wash to the north, the diabase dike has been repeated by faulting and the lower contact is offset 2 to 3 m by a steep normal fault. There are excellent short-fiber (0.5 to 1.25 cm) veinlets above and to the left of the javelina lair. (Don't disturb the wild bee hive high on the outcrop to the right!)

As you return to the vehicles, notice the mine spill high on the north bank. If you have poked around a little to the west of the north outcrops, you have seen some old mine workings that look epithermal -- cockade quartz, open-space filling, fault-vein control. These epithermal aspects figure into the next stop. (J.M.G.)

We will retrace our road to the Y just short of the San Pedro River ford and bear left up the hill and across the railroad tracks into the Ashton Company's flux rock quarry, mostly for a quick look at mining methods. (1.6)

86.3 Park at Ashton Company quartzite quarry.

Stop 10 Troy Quartzite Quarry

The younger Precambrian Apache Group includes the Dripping Spring Quartzite below the Mescal Limestone and the Troy Quartzite above it. This quarry is in the Troy, which is mined, crushed, and railed to the San Manuel smelter for flux rock. Flux is added to the matte-melt in the converters toward the end of its processing. It provides silica to partition the silicophile elements, principally Fe, out of the copper matte into a pseudo-magma that floats on the molten blister copper in the converters. The scum is tapped off as slag, thereby purifying the matte with respect to Fe, Mg, and

Ca. The slag crystallizes when poured out onto the slag dumps as black aa-like pyroxenoids.

This operation mines the clean Troy Quartzite, with credits from a few ppm silver, copper, or gold from the epithermal veins mentioned above, for shipment to Magma Copper's San Manuel smelter. We will take a few minutes to look at the quartzite, and (or) the equipment used to mine, crush, and move it. (J.M.G.)

Return to Rt. 77. (1.0)

87.3 Go right (south) on Rt. 77 through Mammoth, past the San Manuel intersection, to a paved road that turns back Sharply to the right (Old Rt. 77). (19.1)

106.4 Take Old Rt. 77 to the right. (3.3)

109.7 Park at landscaping materials quarry.

Stop 11 Kalamazoo Landscaping Materials Deposit

Landscaping Materials in Arizona and The Kalamazoo Deposit

Robert L. Hockett

Introduction

In retrospect, Arizona is an obvious place for the development of a landscaping materials industry. A high rate of population growth and limited water supplies mandate the development of low water consumption landscaping techniques.

Early residents of the area, before the pressure on available water resources, commonly took advantage of the climate and developed a near tropical look or imported the broad-leafed, water-loving plants of their place of origin. These approaches are becoming less viable.

Historically, I am sure there have been limited applications of landscape rock particularly where uniform appropriate materials were close at hand. An example could be the volcanic cinders available near Flagstaff and along the southern part of the Colorado Plateau. As an industry, the beginning was really in the Phoenix area about 30 years ago. At that time a number of organizations began supplying decomposed or crushed granite for landscaping purposes. The company and operation we are visiting today reflect the culmination of these trends and influences.

Kalamazoo Materials, Inc. and the nominal parent company, Able Earth Environmental Design Co., are both 60 percent owned by Paul D'Allessio. The company dominates the Tucson wholesale landscaping materials market, is a major supplier in Phoenix and Las Vegas, and touches the San Diego market. It operates major quarries at San Manuel, Superior, and Mineral Park. The operation started at San Manuel.

The window of opportunity that started this operation was serendipity brought about by the copper crunch of the Eighty's. Magma's CEO then was Brian Woolfe. Around 1986, he was looking for ways to make money without spending money. Among the suggestions brought forward was the sale of landscaping materials. Although some screened by-products of the flux mining operations had been used for landscaping on Magma's property, it was decided to explore the potential for native plant salvage first. The steady expansion of the tailings disposal area and the subsidence area over the underground operation continually engulfed various native vegetation species. In addition, planning was in progress for the development of the various oxide processing facilities which would involve hundreds of additional acres. Environmental regulations mandate an effort to facilitate the salvage of native species. Ultimately many plants have been moved, but this does not generate significant income. Continuing efforts focus primarily on various cactus species.

One of the landscapers invited to assess the plant potential was Paul D'Allessio. During his tour, he noted the presence of decomposed granite in a number of different shades. He had just previously hauled a large quantity of decomposed granite from Apache Junction to Tucson for some landscaping contracts he was fulfilling. In brief, this led to negotiations culminating with his being granted a license to mine landscaping materials on Magma's property for five years. This license has since been extended. Paul established Kalamazoo Materials to handle this business.

Geology

The Kalamazoo deposit is in what is locally known as the Purcell window. It is an exposure of Precambrian Oracle Granite in a terrain composed largely of the Tertiary Cloudburst Formation and Gila Conglomerate. The Kalamazoo landscape material deposit overlies the Kalamazoo sulfide copper deposit, which is the downfaulted part of the San Manuel orebody. The granite is cut by Precambrian diabase and aplite, Laramide porphyries,and Tertiary rhyodacite. The granite has been mineralized and is deeply weathered.

Operation

Variations in mineralization and weathering give rise to the variations in color. The best red present is actually a red stained grit with erratic large round granite cobbles that has been deposited at the contact on the east edge of the window. Because the granite is so deeply weathered, the only processing required is ripping and screening. Harp wire screens are employed to give close sizing in the finer materials. Paul has crushers available if needed. Cobbles are commonly stacked on mesh enclosed pallets and sold for rock work applications.

Because mining has begun in Magma's Kalamazoo orebody, the copper company has excluded Paul from the prime source of red material for safety reasons. Occasionally, as mining by the caving technique progresses, there have been sudden collapses of large areas of the surface. Surface caving effects are now well developed and it is obvious that no large voids have developed between the undercut and the surface. Mining the surface could be resumed safely using the same techniques Magma does in its oxide open pit over the actively subsiding San Manuel orebody.

Production

Kalamazoo Materials production from this area has been between 4,000 and 8,000 tons a month. Paul has paid Magma approximately one-half million dollars in royalties since 1986. While this is insignificant to a company that produces one-half million pounds of copper from this underground operation alone on a daily basis, when the landscaping operations began, copper could not be sold at a profit.

Return to Rt. 77 via Old Rt. 77. (3.3)

113.0 Turn right on Rt. 77 and return to Tucson. (37.6)

150.6 End of road log.

References Cited

Balcer, R.A., 1984, Stratigraphy and depositional history of the Pantano Formation (Oligocene-early Miocene), Pima County, Arizona: Tucson, University of Arizona, M.S. thesis, 107 p.

Bikerman, Michael, and Damon, P.E., 1966, K-Ar chronology of the Tucson Mountains, Pima County, Arizona: Geological Society of America Bulletin, V. 77, p. 1225-1234.

Bateman, A.M., 1923, An Arizona asbestos deposit: Economic Geology, v. 18, p. 663-680.

Bates, R.L., 1969, Geology of the Industrial Rocks and Minerals: New York, Dover Publications, Inc., 459 p.

Cooper, J.R., 1973, Geologic map of the Twin Buttes quadrangle, southwest of Tucson, Pima County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-745, scale 1:48,000.

Dickinson, W.R., 1991, Tectonic setting of faulted Tertiary strata associated with the Catalina core complex in southern Arizona:

Geological Society of America Special Paper 264, 106 p.

Dickinson, W.R., and Shafiqullah, M., 1989, K-Ar and F-T ages for syntectonic mid-Tertiary volcanosedimentary sequences associated with the Catalina core complex and San Pedro trough in southern Arizona: Isochron/West, no. 52, p. 15-27.

Drewes, Harald, 1971a, Geologic map of the Mount Wrightson quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-614, scale 1:48,000.

_____ 1971b, Geologic map of the Sahuarita quadrangle, southeast of Tucson, Pima County, Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-613, scale 1:48,000.

_____ 1972, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geological Survey, Professional Paper 748, 35 p.

_____ 1980, Tectonic map of southeast Arizona: U.S. Geological Survey Miscellaneous Investigations Series Map I-1109, scale 1:125,000.

Drewes, Harald, and Cooper, J.R., 1973, Reconnaissance geologic map of the west side of the Sierrita Mountains, Palo Alto Ranch quadrangle, Pima County, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-538, scale 1:24,000.

Lipman, P.W., and Fridrich, C.J., 1990, Cretaceous caldera systems - Tucson and Sierrita Mountains, in Gehrels, G.E. and Spencer, J.E., eds., Geological excursions through the Sonoran Desert region, Arizona and Sonora: Arizona Geological Survey Special Paper 7, p. 51-65.

Lipman, P.W., and Sawyer, D.A., 1985, Mesozoic ash-flow caldera fragments in southeastern Arizona and their relation to porphyry copper deposits: Geology, v. 13, p. 652-656.

Percious, J.K., 1968, Geology and geochronology of the Del Bac Hills: Tucson, Arizona Geological Society Guidebook 3, p. 199-207.

Ross, Malcolm, 1987, Minerals and health -- the asbestos problem, in Peirce, H.W., ed., Proceedings of the 21st forum on the geology of industrial minerals: Tucson, Arizona Bureau of Geology and Mineral Technology, Special Paper 4, p. 83-89.

Spencer, J.E., and Reynolds, S.J., 1989, Middle Tertiary tectonics of Arizona and adjacent areas, in Jenney, J.P., and Reynolds, S.J., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest 17, p. 539-574.

Wilcox, D.R., and Larson, S.M., 1979, Introduction to the Tumamoc Hill survey: Tucson, Arizona State Museum, The Kiva, V. 45, p. 1-14.

Yarnold, J.C., and Lombard, J.P., 1989, A facies model for large rock-avalanche deposits formed in dry climates, in Colburn, I.P., Abbott, P.L., and Minch, John, eds., Conglomerates in basin analysis: Pacific Section, Society of Economic Paleontologists and Mineralogists Book 62, p. 9-31.

MINERAL ECONOMICS OF INDUSTRIAL MINERALS IN SOUTHEASTERN ARIZONA

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February, 1992

ABSTRACT

Arizona industrial mineral production is summarized and potential for future development of industrial mineral deposits in Arizona is discussed. Industrial mineral commodities corresponding to each field stop are reviewed. Operations, industries, and markets for each are presented. Commodities included are diatomaceous earth, gypsum, granitic landscape aggregates, calcium carbonate marble, clays, construction aggregates, and portland cement.

ARIZONA INDUSTRIAL MINERALS - PAST AND PRESENT

Throughout Arizona's mineral resource development history industrial minerals have dominated over the metals for most, but not recent, years. The State's metal mining industry that makes Arizona the number one mining state in the United States is a relatively young phenomenon. What we now call Arizona was an important industrial mineral producer long before the metal mining industry got started. Salt, phosphates, silicates, and oxides as food additives, tanning chemicals, gemstones, components of ordnance, pigments, and construction materials are among the minerals produced long before copper, gold, silver, molybdenum, and the other metals became important. Arizona's 1990 industrial mineral production of nearly $300 million ranks 22nd in the nation and higher than the total mineral production of 17 states. The State produces a large variety of industrial minerals as shown in Table 1.

Table 1. Industrial Minerals Currently Produced in Arizona

Ball clay	Hectorite clay
Bentonite clay	Industrial silica sand
Chabazite (zeolite)	Limestone for cement, lime
China clay	Marble dust
Clinoptilolite (zeolite)	Micaceous hematite
Construction aggregate	Perlite
Crushed basalt	Pumice
Crushed dolomite	Pumiceous rhyolite
Crushed granite	Pyrite
Crushed marble	Salt (sodium chloride)
Crushed quartz	Sandstone dimension stone
Crushed rhyolite	Saponite clay
Crushed schist	Schist dimension stone
Decomposed granite	Silica flux
Gemstones	Smelter slag
Gypsum	Volcanic cinders

ARIZONA INDUSTRIAL MINERALS - FUTURE

The future of industrial mineral production in Arizona is positive. Population growth in Arizona and southwestern U.S. market areas will demand more higher quality industrial minerals than Arizona can supply. A current project of the Arizona Department of Mines and Mineral Resources is accelerating this positive future.

Table 2. Industrial Minerals Previously Produced in Arizona

Asbestos	Muscovite mica
Barite	Pozzalon
Diatomite	Quartz cobbles
Diopside	Quartz crystals
Solomite	Red iron oxide pigment
Feldspar	Sericite mica
Fluorspar	Sodium sulfate
Granite dimension stone	Tufa dimension stone
Kaolin-silica stone	Tuff dimension stone
Marble dimension stone	Williamsite

A number of additional industrial minerals have been produced previously and might be producible again. They are listed in Table 2.

Other industrial minerals known to occur in Arizona that may be produced in the future are listed in Table 3.

Table 3. Other Industrial Minerals Known to Occur in Arizona

Alunite	Potash
Anhydrite	Pyrophyllite
Biotite mica	Rutile
Brucite	Vermiculite
Garnet	Wollastonite
Ilmenite	Zircon

The Arizona Department of Mines and Mineral Resources is compiling data to encourage the development of industrial mineral deposits in Arizona. The manufacturing industries of Arizona and those manufacturing centers within a reasonable shipping distance, especially Southern California, use a large quantity of industrial minerals that are currently shipped to the southwestern states at considerable transportation cost. The development of deposits and processing operations for these minerals in Arizona could have a number of beneficial effects.

The State economy would benefit from increased employment and tax base and manufacturers would benefit from increased availability of raw materials and possible lower prices, due to reduced transportation costs, increased competition, and potential substitution.

A series of reports on industrial mineral consumption in a number of Arizona and Southern California industries is being prepared. Emphasis is being placed on finely ground minerals used as functional fillers. Although deposits are believed to exist in Arizona, currently only limestone is being produced for filler applications. We believe that by quantifying consumption, reporting specifications, and explaining uses of minerals in various industries, sufficient demand will be shown to justify new development of nonmetallic mineral deposits in Arizona.

A large variety of industrial minerals as functional fillers are being considered. They are listed in Table 4. Though not all of these minerals are expected to occur in exploitable deposits, many have possible substitutions that may be developable in Arizona.

Table 4. Functional Fillers

Alumina compounds	Mica
Asbestos	Nepheline syenite
Attapulgite clay	Perlite
Barite	Pumice
Bentonite clay	Pyrophyllite
Brucite	Rock dust
Diatomaceous earth	Silica
Feldspar	Talc
Kaolin	Wollastonite
Limestone	Zeolite
Magnesite	

The project is being conducted on an industry-by-industry basis to speed the gathering of data. Industries to be surveyed are given in Table 5.

Table 5. Industries to be Surveyed

Abrasives and polishes	Ink
Asphaltic roofing materials	Insecticides
Ceramics	Livestone & pet feeds
Chemicals	Paint
Cosmetics & toiletries	Paper
Cultured marble & granite	Plastics
Elastomeric coatings	Rubber
Fertilizers	Textitles
Fiberglass	Thermal insulation
Food processing, additives	Wallboard joint cement
Foundry fluxes, supplies	Water filtration
Glass	

The principal source of information for these reports is direct discussions with manufacturer/consumers using industrial minerals and distributors of industrial minerals. The data is being gathered, compiled, and the reports written by the author.

The reports will include a description of the subject industry structure, quantities of industrial minerals consumed, typical specifications of minerals used, possible substitution minerals, and other factors which may impact the future demand for minerals. Prices and transportation costs are also discussed.

Input is requested from the minerals industry. Suggestions of industries or commodities of particular interest are encouraged, as are comments regarding the content of the reports. The author is available to discuss the project and preliminary data.

Four reports have been completed and released as open file reports:

Industrial Minerals in Arizona's Paint Industry: Open File Report 89-1

Industrial Minerals in Arizona's Wallboard Joint Cement Industry: Open File Report 89-2

Industrial Minerals in Southern California's Wallboard Joint Cement Industry: A Potential for Mineral Development in Arizona: Open File Report 89-3

Industrial Minerals in Arizona's Cultured Marble Industry: Open File Report 91-6

The four subject industries consume approximately $22 million of industrial minerals as functional fillers and extenders. Prices paid by users of minerals delivered to their plants range from a low of $33 per ton for ground limestone to Southern California joint cement manufacturers to a high of $1400 per ton for specialty mica delivered to a Tucson paint manufacturer. Many of these minerals are shipped into Arizona and Southern California from the Atlantic coastal states and eastern Canada.

Additionally, data has been collected from portions of a number of other industries in Arizona and Southern California. The current status of industrial minerals consumption data in various industries in Arizona and Southern California is detailed in an open-file report (OFR92-9, at the time of this paper). The collection of consumption and market data by user contacts is continuing. The report details the raw data collected for this Arizona Department of Mines and Mineral Resources project in spread sheet form. Although the industries and commodities are briefly defined, the report contains no text. Once all users in a particular industry have been interviewed, the information is compiled and the industry and commodities are described in the appropriate industry series. This open file report is updated 2 to 4 times a year.

Direct contact has been made by personal visit or telephone to each manufacturer. In addition to collecting data, such contact has provided the opportunity to familiarize consumers with Arizona's mining industry and mineral potential. As a direct benefit, it has also resulted in some additional markets for current Arizona mines.

The consumption of industrial minerals targeted in this project in Arizona may be sufficient to justify a small specialized multimineral producer operating a number of small mines, each producing a specific mineral, but utilizing a common grinding/processing plant. Many of the minerals used in one industry have nearly the same specifications as those used in others. Thus a multimineral producer could produce for more than one Arizona industry. Further, Southern California is a large market for industrial minerals. It is expected that investigation of industries in Arizona and Southern California will yield consumption data that will produce totals of sufficient quantities to justify development of new mines in Arizona.

ARIZONA INDUSTRIAL MINERALS - FACTS AND PROBLEMS

Over the last four years, forums and meetings have been held to discuss and address some of the difficulties facing the industrial minerals mining industry in the Southwest. A few quotations from each will provide a flavor of these difficulties.

From Peirce, H.W., in Tooker, E.W., 1989, *Arizona's Industrial Rock and Mineral Resources-Workshop Proceedings,* U.S. Geological Survey Bulletin 1905, 93p.

> "Even though about 13 tons of nonmetallic mineral materials is produced yearly per Arizona resident, the importance of these resources remains generally unappreciated, in contrast to those of the metallic mineral commodities. Although we no longer make many of our tools out of stone, a sophisticated civilization relies heavily on a continuous flow of an increasing array of useful nonmetallic mineral materials."

> "...pressures are mounting to restrict the locations of sand and gravel operations. Construction on flood plains, building of large bridges, and channel stabilization projects combine to restrict the locations of sand and gravel mining. Government policy development regarding this resource should begin to recognize (1) the necessity of an active sand and gravel industry and (2) the need to locate and protect those resources for the future."

From Eyde, T.H., in Tooker, E.W., 1989, *Arizona's Industrial Rock and Mineral Resources-Workshop Proceedings,* U.S. Geological Survey Bulletin 1905, 93p.

> "Expanding the use of industrial mineral resources is based on three factors: (1) the market place, (2) the specifications of the materials, and (3) the political and environmental scene. Most performance or high value added minerals are relatively insensitive to transportation costs. Geology actually plays a subordinate role in the economic development of these resources. Arizona is a rapidly growing state with a population now passing the 3 million mark. It is adjacent to California, a huge state that has the sixth largest economy in the world. California also has the most stringent environmental laws of any state in the West. This location may mean that Arizona will be a prime area for developing the industrial materials which now cannot be produced in California."

From Griggs, G.W., in Tooker, E.W. and Beeby, D.J., 1990, *Industrial Minerals in California: Economic Importance, Present Availability, and Future Development*, U.S. Geological Survey Bulletin 1958, 127p.

> "California is both a major producer and consumer of industrial minerals. More than 50 industrial minerals, and more than 200 million tons of these minerals with a value at the mine of more than $2 billion, are produced annually in California." "When refined and delivered to the customer, this value is two or three time higher, possibly $5 billion. These raw material building blocks of the economy represent almost 10 percent of all goods and services produced in California."

ARIZONA INDUSTRIAL MINERALS - COMMODITY OVERVIEW OF DEPOSIT VISITS

Each of the industrial minerals commodities within the area of the field trip are discussed in this section.

Diatomite

Diatomite, or diatomaceous earth, is a sedimentary rock composed of a high proportion of the microscopic-size shells of minute water-dwelling plants or algae called diatoms. It is also known as infusorial earth, kieselguhr, and fossil flour. The frustules or shells of the diatoms are siliceous, opallike skeletons containing pores and channelways that give them internal porosity and permeability. Major uses are for filtration, fillers, thermal insulation, and numerous miscellaneous uses including absorbents, pesticide carriers, light-weight aggregates, ceramic materials, floor sweep compounds, and anticaking agents. Diatomite can also be used as a source of silica for glass and metallurgical applications. However, opaline silica is considered detrimental in construction aggregates used in making some concretes.

Although occurrences of diatomaceous sedimentary rocks in the western United States are numerous, only selected deposits are exploited. Because of the variability of diatoms, the suitability of any given deposit for particular uses require extensive testing. Further, the nature and distribution of impurities such as volcanic ash, sand, clay, chert, limestone, and various colored oxides affect the potential end uses, processing requirements, and value. Diatomite of particular specifications can bring relatively high prices.

In addition to the White Cliffs deposit and others in the immediate area of Pinal County, there are deposits of diatomite found associated with gypsum in Cochise and Yavapai Counties. Diatomite occurrences are also located in Graham and Greenlee Counties.

The White Cliffs Mine has been Arizona's important producer. Its output has been used for filter aids, fillers, and cement additives. Diatomite is not currently being mined in Arizona.

The White Cliffs deposit has been mined by a number of ventures over the last 60 years. Most markets have been localized or for lower value products, even though the potential success of most of the operations were based on selling high value filter aid and specialty paint fillers.

Processing methods have consisted of crushing crude material, drying to about 1 percent moisture, sizing in dust collectors, grinding of dust collector over size, and resizing with dust collectors in closed circuit with grinding to produce a -325 mesh product. At various times coarser size products have also been produced such as - 0.125" for agricultural applications.

The average price for processed diatomite produced in the United States in 1990 was $199 per short ton at the processor's plant. Material from the White Cliffs mine in the last year of operation was for considerably less. It is believed that the quality of processed diatomite produced at the White Cliffs mine fell short of that required for most high value uses. The December, 1991 *Industrial Minerals* magazine reports typical delivered prices of calcined filter-aid quality U.S. produced diatomite to United Kingdom consumers at the equivalent of $500 per short ton. Arizona Department of Mines and Mineral Resources Open File Report 89-1, *Industrial Minerals in Arizona's Paint Industry* reports that Arizona paint manufacturers are paying $522 to $592 per short ton for paint-filler grades. A typical specification for fine ground diatomaceous earth or diatomite used in paint is shown below:

TYPICAL PARTICLE SIZE DISTRIBUTION

Retention on 325 mesh screen	3.0%
Mean particle size (Equivalent Spherical Diameter)	5.2 Microns

TYPICAL PHYSICAL CHARACTERISTICS

Color	Cream
Brightness	72
Specific gravity (Effective)	2.2
Moisture	6.0 %
ph Factor	6.5-8.5
Water absorption (weight %)	250
Oil absorption (weight %)	180
Hegman grind	4
Specific surface area	4.5 m^2/gm

Gypsum

Gypsum is a hydrous calcium sulfate that normally occurs as a soft, compact, granular rock. Its chemical symbol is $CaSO_4.2H_2O$. It also occurs as a fine-grained massive and sometimes translucent form called alabaster. Further, a number of mineralogical forms, varieties, and associations exist, such as selenite, satin spar, and gypsite. Gypsum may be colorless, white, gray, or in hues of red, yellow, or brown. Pure gypsum contains 32.5 percent lime (CaO), 46.6 percent sulfur trioxide (SO_3), and 20.9 percent water.

Anhydrite, $CaSO_4$, is a closely related mineral and contains 41.2 percent CaO and 58.8 percent (SO_3) with no water of hydration.

The gypsum of commerce is the compact, massive, finely crystalline to granular rock containing at least 80 percent gypsum. For many uses gypsum rock must contain at least 90 percent gypsum. Impurities usually include interbedded limestone, shale, dolomite, clay, and salts. Gypsite, which may contain as little as 50 percent gypsum mixed with the other impurities mentioned, can be used for some agricultural applications. Alabaster, which is a comparatively rare form, has been used for centuries for carving into lamp bases, bowls, and similar objects. The varieties selenite and satin spar have no unique industrial uses. However, selenite and satin spar when found as attractive specimens are prized by collectors.

On an industry-wide basis about one fourth of the gypsum consumed is as crude gypsum while the majority is calcined. In Arizona, the proportion of gypsum calcined to that used uncalcined is about equal. Uncalcined gypsum is added to portland cement to retard setting time. It is also added to soil in agricultural areas where calcium and sulfur are required or to break down the sodium content of alkali soils.

Calcining gypsum produces either plaster of Paris when roasted at temperatures of 250°F - 600°F or "dead-burned gypsum" when roasted at temperatures of 900° - 1000°F. Plaster of Paris, when mixed with water, forms an easily worked plaster that recrystallizes to gypsum. It is used directly as plaster or it can be molded between sheets of heavy paper to form gypsum board (also called wall board, sheetrock, or plaster board). Plaster of Paris is also used for making casting molds and in many applications as a binder, filler, or chemical agent. Dead-burned gypsum, which is chemically identical to anhydrite, is used as a desiccant and dehydrator and in specialty cements.

Gypsum has been produced commercially in Arizona since about 1880, but has been an important mineral commodity only since the mid 1950's when demand for its use in agriculture and construction increased substantially. Current production is from the Camp Verde area of Yavapai County, the Littlefield area of Mohave County, the Harquahala Mountains near Salome, and the Winkleman-Mammoth area of Pinal County.

The quantitative production and value details of Arizona's gypsum mining industry are kept proprietary to protect individual company data. The Arizona Department of Mines and Mineral Resources estimates total gypsum production for Arizona at 400,000 short tons with a mine value of $3 million. At least five companies produce gypsum in Arizona. They are in decreasing order of production: National Gypsum Company, Superior Company, Western Gypsum Company, Pinal Gypsum Company, and Western Organics Incorporated. These five companies operate six mines.

Production by National Gypsum from the Winkleman-Mammoth area of Pinal County is for their Gold Bond Building Products wallboard manufacturing plant in Phoenix. National Gypsum is the only operation calcining gypsum in the State. Superior Company's production from both the Winkleman-Mammoth area and the Camp Verde area is primarily for the cement plants at Rillito and Clarkdale respectively. They also supply a small quantity for local agricultural use. Western Gypsum's production from the Littlefield area is shipped to Nevada and California for cement additives, agriculture, functional fillers, and water treatment. Pinal Gypsum Company's production from the Winkleman-Mammoth area is sold for agricultural use. Western Organic's production is used for agriculture and the manufacture of horticultural supplement and premixed packaged potting soils.

The only Arizona gypsum consumption data available for public disclosure is for agricultural application; 64,400 short tons in 1990.

The average mine value of crude gypsum produced in Arizona is $7.50 per short ton while that for calcined gypsum is $17.00. Prices for agricultural gypsum are in the range of $20 to $40 per ton delivered and applied to crop fields. This price is for - 0.125" gypsum assaying over 90 percent $CaSO_4.2H_2O$. Farmers in western Maricopa County report paying $30 per short ton for finely crushed agricultural gypsum applied to their fields (including cost of application). Individual loads of agricultural gypsum bulk loaded on the consumer's truck at the supplier's yard are reported to sell at $40 per short ton.

Suppliers of agricultural gypsum, as with other "fertilizers" are required to pay a $0.25 per ton tax to the State Chemist within the Arizona Department of Agriculture. The State Chemist certifies the guaranteed minimum analysis of the effective ingredient, which for gypsum is $CaSO_4.2H_2O$, and guaranteed maximum content of any detrimental ingredients.

Resources of gypsum in Arizona are extensive with deposits existing in most counties.

Important factors in considering gypsum deposits are their location relative to markets or areas of consumption (and easy transportation), and their development/mining costs. The grade of the deposit must also be considered, particularly the type and amounts of impurities. Generally, the higher the gypsum content, the better, and a lower grade deposit serving the same market as a higher grade one will have little value.

Most gypsum operations require limited mineral processing. Grade control is done by selective mining. Beneficiation, other than that accomplished by screening, is seldom used when the product is uncalcined gypsum for agricultural, horticultural, or cement additive uses. Crude gypsum is simply crushed and screened to the customer's size requirement. Crude gypsum that is to be calcined may require limited beneficiation and as well as sizing.

Gypsum mined by National Gypsum is shot, screened to remove contaminating dirt, crushed to -4", and loaded into trucks for shipment to the company's Gold Bond wall board plant in Phoenix. Before calcining at Phoenix, it is further reduced in size with hammer mills. The gypsum is then calcined at nearly 600^{0}F to make plaster of Paris. Water is added to the plaster of Paris and the wet mixture is cast between layers of craft paper. The added water allows the plaster of Paris to recrystallize to gypsum forming a continuous rock-like sheet between the craft paper layers. The resultant sheets are cut to consumer-specified lengths and shipped to construction job sites or building material distribution centers.

Gypsum mined by Pinal Gypsum for agricultural use is dozed into piles and shipped to the company's yard in Coolidge. There it is screened to -.125", loaded into spreader trucks, transported to the customer's fields, and applied. Oversize material is stockpiled at the company's yard and contract crushed when needed.

The gypsum calcining plant at National Gypsum's Gold Bond facility is the only one in Arizona. All plaster of Paris, casting plaster, and stucco is imported from other states.

Landscape Rock

Landscape rock can be described as any crushed, broken, or quarried blocks of rock, and natural boulders used out of doors for ground cover and decorative purposes. Included is naturally crystalline rock that has weathered to produce a "decomposed granite" type material.

Landscape rock and decomposed granite are lumped together and with all other forms of crushed and broken stone by the U.S. Bureau of Mines for statistical data gathering purposes. Thus, tonnage, total value, and typical unit value published includes material ranging from construction fill and levee rip-rap through landscape materials to finely ground filler-extenter minerals. Production for 1989 was 6,649,000 short tons valued at $28.55 million ($4.29/ ton average), and for 1990, 5,300,000 short tons valued at $13.50 million ($2.55/ ton average). Since the 1990 quantities and values are only estimates based on national trends, I doubt they are correct because no one is going to quarry, crush, size, and sell rock for $2.55 per ton.

There are at least five producers of crushed and/or decomposed granite for landscape uses in Arizona. In 1989 they produced 1,092,000 tons valued at $3,413,000 for an average mine value of $3.13 per ton.

The major market for crushed and decomposed granite produced in Arizona is the urban and suburban areas of Tucson, Phoenix, and Las Vegas. Material for the Tucson market is produced at San Manual; that for Phoenix is produced from outcrops and pediments surrounding the Salt River Valley; and that for Las Vegas from the Mineral Park area of Mohave County.

Crushed and decomposed granite are both aesthetical and functional when used in landscape applications. Functional properties include ground cover to limit dust, reduce water use and evaporation, and weed control. Aesthetically, crushed and decomposed granite are alternatives to bare dirt or vinyl mulch. The deep weathering that produces decomposed granite yields a material that packs well to make a relatively smooth competent surface for driveways, play areas, and tennis courts. "Clay court" tennis courts, in reality, are spread, rolled decomposed granite.

Crushed granite is produced by quarry methods involving drilling and blasting of production benches, crushing, and screening to provide marketable products. Most decomposed granite deposits do not require blasting, and many do not require crushing.

Market factors include distance to market (transportation is usually the larger portion of delivered cost), color, and particle size. Available particle sizes often include -.5"+.25", -.25"+.125", and -.375" (when excessive fines are not a factor). Colors are various shades of white, gray, tan, gold, red, and brown. Shades in the red-pink range are the most popular. Additional colors, (especially shades of greens and blues) when available, are considered special and usually command special prices.

Marble and Limestone

Limestone, dolomite, and marble are calcium and calcium-magnesium carbonate rocks that are very important and useful in the construction industry and for chemical and industrial use.

Pure limestone is 100 percent calcite $CaCO_3$ and pure dolomite rock is 100 percent dolomite $CaMg(CO_3)_2$. Neither rock often occurs pure in nature as dolomite substitutes for calcite in limestone and calcite substitutes for the mineral dolomite in dolomite rock. The names "limestone" and "dolomite" include rocks consisting of at least 80 percent carbonate without regard to whether the carbonate is calcite, the mineral dolomite, or a combination of both. Calcite greatly predominates in limestone and dolomite predominates in dolomite rock. When calcite and dolomite are present in more or less equal proportions, the rock is termed a magnesian limestone. High calcium limestone contains at least 95 percent calcite.

Marble, which is limestone or dolomite that has been naturally recrystallized, often has the same chemical and mineralogical composition as the original carbonate rock or it may contain new minerals formed during the metamorphic process. Marble is almost always more coarsely crystalline than the original carbonate rock. An economically important physical quality of some marble is its ability to take a smooth polish and thus be marketable as dimension, facia, or monument stone.

Uses for limestone and dolomite or marble of either composition include: (1) crushed stone for concrete aggregate, road material, railroad ballast, and in its finer form, for poultry grit, stucco, functional fillers and extenders, and whiting agents; (2) as a fluxing agent in smelting and refining metals; (3) as a soil conditioner in those parts of the country where soil acidity is a problem (not, however, in the arid Southwestern United

States); (4) as a source of lime; (5) as a chemical raw material in glass making, acid neutralization and other processes; and (6) as dimension stone. Limestone, but not dolomite, is used as the basic raw material in the manufacture of portland cement. Dolomite, but not limestone, is an important ingredient in high grade refractories.

In Arizona limestone and limestone marble is used as crushed stone, sized sand and fillers-extenders, as feed for lime plants, and for the manufacture of portland cement. Dolomite is used as railroad ballast in part of the State. Lime is manufactured for export from the State as well as for mineral processing and numerous industrial and construction applications within Arizona. Limestone as crushed and ground material is used to treat stack gases from electric generating plants and copper smelters and to a lessor extent to neutralize excess acid recovered at copper smelters. Limestone is mined and consumed by both of the State's cement plants in the manufacture of cement. Marble is used as landscape rock, roof granules, poultry grit, livestock feed supplements, functional fillers, decorative and monument stone, and dimension stone.

There are many deposits of limestone, magnesian limestone, dolomite, and marble in Arizona. However, only a few have been or can be exploited for commercial uses because of location, size, or quality of material. The best Arizona limestones for chemical and industrial use are Mississippian, Pennsylvanian-Permian, and Cretaceous in age. The two best limestones for overall purity, thickness, and availability over wide areas are the Escabrosa and Redwall Limestones of Mississippian age and most current operations are in these limestones.

The marble quarries in the Santa Rita Mountains provide landscape aggregates, poultry grit, swimming pool plaster sand, livestock feed supplement, and functional fillers-extenders. This Arizona industry has received recent national interest with the acquisition of locally owned operations by national industry giants. Pfizer Specialty Minerals has acquired the Santa Rita quarry and mill operations from Calcium Products of Arizona and Georgia Marble has acquired Andrada Marble Company's Andrada Marble Quarry. Both Pfizer and Georgia Marble plan modernization and expansion at their recent acquisitions. These acquisitions are, in part, if not in total, a direct result of the Arizona Department of Mines and Mineral Resources project to encourage development of industrial minerals in Arizona.

Limestone, dolomite, and marble are important resources in Arizona. The long term future for these industrial minerals is good. Limestones for cement and other construction uses where its chemical properties are important, for production of lime, and for quality dimension stone have an attractive future in the Southwest.

There are at least four Arizona producers of crushed and/or milled limestone and marble for noncement and nonlime uses. In 1989 they produced 62,500 tons valued at $865,700 for an average mine value of $13.85 per ton.

With Pfizer's acquisition of Calcium Products of Arizona, a number of speciality coarse-sized and fine-milled marble products have become available to Arizona and southwestern United States consumers and manufacturers from a local source. Table 6 lists Pfizer's available products for purposes of example.

Operations at the Santa Rita Quarry and mill consist of an open pit mine, crushing-screening plant, mills, and ancillary facilities. In the quarry the coarsely crystalline marble is drilled, shot, and loaded into mine trucks for a downhill haul to the crushing and mill plant. At the plant, mine run material is crushed and screened to produce landscape rock, and fine crushed and screened to make poultry grit and marble sand. The crushing and screening plant also produces minus 0.625" material to feed the Raymond roller mills. The Raymond roller mills in closed circuit with air cyclone classifiers are used to produce the finely ground marble filler grades. The various products

PRODUCT	COMMERCIAL LOT PRICES	SIZE	USES
Marblewhite A 4500	Bagged, $70.00/ton	100% minus 325 mesh, Controlled brightness and particle size	Filler for flat paints and coatings
Marblewhite A 325	Bagged, $49.00/ton Bulk, $29.00/ton	98% minus 325 mesh	Filler for less critical applications than Marblewhite 4500, such as calcium in liquid feed supplements
Marblewhite A 220	Bagged, $47.00/ton Bulk, $28.00/ton	Minus 200 mesh	Filler in dark colored products such as asphalt pavement crack sealants
Marblewhite A 50	Bagged, $43.00/ton	Minus 50 mesh	Filler for cultured marble
Calcium Grits A 69	Bagged, $48.00/ton Bulk, $28.00/ton	A 50:50 blend of 0.25" and 30 mesh to 0.125" marble sand	Poultry feed calcium supplement and digestive aid (grit)
Marblemix A	Bagged, $46.00/ton Bulk, $29.00/ton	Minus 30 mesh	Swimming pool plaster sand
Viroc A #1	Bulk, $12.00/ton	Typical 0.625"	Decorative rock for landscaping and roofing rock
Viroc A #2	Bulk, $12.00/ton	Typical 0.875"	Decorative rock, landscape rock, and acid neutralization

Table 6. Examples of available products from Pfizer's Santa Rita Marble mine.

are either conveyed to stockpiles for the coarse materials or blown or lifted to silos for fine products. A bagging plant is fed from the silos and bulk trucks are also loaded from the silos. The coarse landscape material is loaded into trucks with a front end loader.

The new capital investment and operation of the Santa Rita mine is a direct benefit to Arizona's economy. Further, the availability of a quality raw material from a stable source is a boon to over 100 Arizona manufacturers who previously were dependent on out-of-state or erratic supplies.

Clay

A variety of types of clay are produced in Arizona. Commercial clays may be classified by mineralogy, chemistry, uses, or consuming industries. The U.S. Bureau of Mines reports Arizona as producing nonswelling bentonite, swelling bentonite, and common clay. By use classification, these clays are reported as bentonite clays for oil refining catalysts and clays desiccants, and common clays for floor and wall tile, bricks, portland cement, structural tile, and miscellaneous clay products. The clays of the Pantano wash are classified as common clay for bricks, common clay for structural tile, and common clay for cement. However, a high alumina clay suitable for structural clay products is not a common occurrence.

There are at least ten Arizona producers of clay operating at least 13 mines. In 1990 (according to the U.S. Bureau of Mines) they produced 154,500 short tons valued at $2,318,000 for an average mine value of $18.23 per ton. This U.S. Bureau of Mines data likely does not represent all of the clay produced in Arizona. In 1989 the average value of bentonite mined in Arizona was $42.91 per ton and that of common clay was $4.58 per ton.

The Pantano clay deposit supplies almost half the clay mined in Arizona. This clay deposit supplies a high alumina "fire clay" of mixed kaolinite - illite clay minerals usable as a skeleton former and self-fluxing glass former in structural clay products such as brick and tile. Further, it is the dominant source of color in the bricks and tile in which it used. The Pantano deposit also supplies high alumina clay to the Rillito cement plant.

Ted Eyde in Tooker, E.W., 1989, *Arizona's Industrial Rock and Mineral Resources-Workshop Proceedings,* U.S. Geological Survey Bulletin 1905 had the following comments about the Pantano Clay deposits: "Several years ago, I was an expert witness in court where the Arizona State Land Department contended that the brick clays of the Pantano deposit were a common mineral material.Nevertheless, the Land Department's expert witness conceded that these clays represented the widest range of colors he had ever seen. Moreover, he said that it was the only high alumina clay deposit in the State suited to making good quality facing brick. It is a performance material that is mixed with clay filler from the Tolleson deposit west of Phoenix. The Pantano specialty clay is hauled from Pantano to Phoenix, a distance of 140 miles."

Sand and Gravel

Sand and gravel ranks below only copper and molybdenum in value of production in Arizona. In 1990, 27,915,000 tons of construction sand and gravel worth $92,166,000 was produced at an average mine value of $3.30 per ton. The urban centers of Maricopa and Pima Counties were the largest producers and consumers of construction sand and gravel.

Arizona ranks among the top ten states in sand and gravel production. Based on estimates it ranks number seven. A factor in Arizona's high rank is the State's relative abundance of natural aggregate avialable from alluvium deposits. In many states a large portion of construction aggregates are produced from hard rock deposits. As such hard rock production may be tabulated by the U.S. Bureau of Mines as crushed stone, Arizona's high ranking may not tell the whole story.

There are four major steps to sand and gravel mining; (1) site acquisition and clearing, (2) mining, (3) processing consisting of crushing, screening, washing, and blending materials, and (4) site reclamation.

There were 1,407 production workers involved in mining sand and gravel in Arizona during 1988. These workers created employment for an additional 103,419 Arizona workers whose jobs depended directly on the existence of sand and gravel production. Thus each sand and gravel mining job made possible an additional 73 jobs in related industries.

The value of Arizona construction in 1988 was $3.8 billion. Each $1,000 of inflation-adjusted-construction output requires 11.3 tons of sand and gravel.

Including requirements for pavement, pipes, drains, walls, and overpasses, each mile of urban freeway uses 400,000 tons of sand and gravel. The combined inner and outer loops of the metropolitan Phoenix freeway system to be constructed by the year 2008 will consume 92 million tons of sand and gravel.

The primary uses for sand and gravel include concrete aggregate for buildings, highways, dams, and airports (20%); road bases and coverings (17%); asphaltic concrete aggregate (10%); construction fill (9%); concrete products such as blocks, bricks, and pipes (2%); plaster and gunnite sands (2%); and numerous other uses such as railroad ballast and roofing materials (40%).

During 1988, there were 23,367 single-family houses built in Arizona. A typical 1600 square foot house requires 100 tons of sand and gravel. A 24-story office building requires 36,000 tons, while a regional retail center (mall) requires 100,000 tons.

Ted Eyde, in Tooker, E.W., 1989, *Arizona's Industrial Rock and Mineral Resources-Workshop Proceedings*, U.S. Geological Survey Bulletin 1905, comments on an increasing concern in the aggregate industry.

> "For example, the common material aggregate has been produced in Arizona mainly from streambeds of the Salt River at Phoenix and the Santa Cruz River and Pan-

PORTLAND CEMENT

Blend together:
4 cups good limestone
3 Tbl. high alumina clay or shale
1 Tbl. silica (as sand, sandstone, or calcium silicate)
1 Tsp. iron ore
Grind blended ingredients. Bake at 2700 ° about an hour
Add:
2 Tbl. gypsum to resulting clinker
Grind to powder. Package for sale.

Figure 1. A favorite recipe for Portland Cement.

tano Wash in Tucson. In outlying areas, much sand and gravel production comes from alluvial fans and dry streambeds. But for some uses, sand and gravel is no longer a common material. For example, the prudency audit at Palo Verde nuclear powerplant questioned the $178 million cost of aggregate that was shipped from the San Gabriel Mountains of Southern California to the reactor site. Why was this source of aggregate used? The Salt River gravels contain Cenozoic rocks with inclusions of opaline silica and other minerals, which because of their reactivity would not be appropriate for use in a containment vessel at the reactor. An inspection by an intervener would have required the structure to be replaced."

"... one of the most serious construction problems today is reactive concrete. A good example can be seen in the deterioration of the railings and the structural cracking and crazing of the Tempe Bridge across the Salt River. Since the introduction of such materials as calcium chloride into aggregate, the development of structural cracks have been so serious... ... that many structures have had to be torn down. Thus, aggregate is becoming a performance material with stringent standards ... Aggregate must bond well, so that the filler materials in asphalt and cement lend strength to the final road mix."

Portland Cement

Arizona's cement production capacity of 1.73 million short tons ranks fifth among states west of the Mississippi. Arizona has two portland cement plants. One is operated by Arizona Portland Cement Company at Rillito. The other is operated by Phoenix Cement Company at Clarkdale. Arizona's combined production of portland cement and masonry cement is estimated at 1.3 million short tons worth $80 million; an estimated per ton value of $61. Our cement plants continue to operate well below capacity. They are impacted by both the slump in the construction economy and the practice of Southern California and Mexico cement plants shipping excess production to Arizona.

Limestone for each plant is mined from company owned quarries near their plants. Other raw materials are supplied by independent mines.

Arizona Portland Cement Company's plant produces Portland cement from quarried and purchased raw materials. The Twin Peaks Quarry is about 4 miles west of the plant. The plant is adjacent to both the Southern Pacific Railroad and Interstate 10, about 17 miles northwest of Tucson.

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

Raw materials consist of siliceous limestone, high calcium limestone, high alumina clay, "aluminum catalyst waste", low grade bauxite, floated hematite from Magma Copper Company's Magma Mine at Superior, iron ore (hematite) from Eagle Mountain in California, gypsum, and the fuels; natural gas, fuel oil, coal, coke, used motor oil, and shredded automobile tires.

These materials supply the necessary calcium oxide, silica, alumina, iron oxide, and energy to make cement clinker and the calcium sulfate to control setting and curing properties of the final product.

Raw materials are blended to produce a typical portland cement of the following composition:

Lime, CaO 60-66 %
Silica, SiO_2 19-25 %
Alumina, Al_2O_3 3-8 %
Iron, Fe_2O_3 1-5 %
Magnesia, MgO 0-5 %
Sulfur, as SO_3 1-3 %

Limestone is the source of calcium oxide. The company operates their own limestone quarry 4 miles west of the cement plant. The Twin Peaks Quarry which occupies both a small hill and a pit immediately to the northeast have been developed in a Paleozoic limestone. The limestone is typically siliceous, and contains zones of dolomitic limestone, quartzite, and siltstone.

The deposit is selectively quarried to produce a low magnesia, controlled-silica limestone. Their limestone contains sufficient silica and no outside source of silica is needed. Dolomitic limestone is held to a mininum to keep magnesia as low as possible, and below the maximum allowable limit of 6% MgO. Rock from the quarry that is too high in silica or magnesia is crushed, sized, and sold as aggregate that finds a ready market in the north part of Tucson where most of the sand and gravel deposits are relatively high in sand.

Siliceous limestone from the quarry is crushed to minus 2" and stockpiled for loading on the conveyor for a 4-mile trip to the stacker-reclaimer feed-pile at the plant. Stockpiles of iron ore and high alumina clay or other alumina material are also maintained at the quarry.

Quality control of the raw material blend is the key factor to producing an acceptable final product. The first blending and mixing stage takes place at the quarry. The limestone is drilled and the holes assayed to provide initial data to determine blending of rock from various parts of the quarry. Based on quarry rock assay, clay and iron ore are added to the belt feed so that a proper mix is approximated before it leaves the quarry for the 4-mile conveyor trip to the plant. The conveyor handles 1100-1200 tons per hour. This mix is sampled as it arrives at the stacker-reclaimer stockpiles at the plant. An automatic sampler collects 8% of the belt discharge and provides an hourly sample which is assayed. The results from each hour are used to adjust the blend of the conveyor feed at the quarry.

The conveyor discharge is bedded by a chevron stacker in the stacker-reclaimer building. Chevron stacking followed by stockpile-toe reclaiming further blends the mix. The stacker reclaimer building has capacity for two 32,000 ton stockpiles. While one is being stacked, the other is being reclaimed to supply the raw material grinding plant. Before grinding the raw material blend is again adjusted. The raw materials are fed to a cone crusher to produce minus 0.5" ball mill feed. The raw-feed is ground in a single 15'6" X 21' ball mill, operated dry, in closed circuit with two cyclone classifiers, to produce an 80 percent minus 200 mesh kiln feed. The ground raw materials are again mixed to produce kiln feed.

Kiln feed is fed to rotary kilns through preheaters that use kiln waste heat to preheat the kiln feed. All moisture and water of hydration is driven off and even most calcining of the limestone takes place in the preheators. The preheater discharges into the rotary kilns at the high end of the kilns.

The kiln feed moves through the rotary kilns toward the burner end (also lower end). While en route through the kiln, calcination of the limestone is completed and fusion to a clinker glass takes place. The clinker is discharged at the lower end of the kilns and allowed to cool to ambient temperatures. Gypsum in the range of 5.5% is added to the cool clinker and the mixture is ground to produce the final product.

Stacking, reclaiming, conveying, screening, and mixing takes place within enclosed structures so all dust is collected and reintroduced into the process stream. All discharges from the kilns, preheaters, and clinker coolers is treated by precipitators and bag houses. Water vapor, carbon dioxide from the breakdown of the limestone, and sufficient heat to allow process system heat flow are discharged to the atmosphere.

PRESENT AND PAST PRODUCERS OF WHITE CALCIUM CARBONATE PRODUCTS IN ARIZONA

by

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INTRODUCTION

The statistical information collected by the U.S. Bureau of Mines on calcium carbonate products is published under the limestone classification in the Stone chapter of the Minerals Yearbook. However, carbonates are the most widely used fillers in paints and plastics, and, thus, are an important and sizeable segment of the filler-extender products industry. Also, the trend is toward increased specialization in the production of finely ground, high-brightness calcium carbonate products.

Limestone is one of the most abundant rocks in the earth's crust, nevertheless, deposits of white, high-purity limestone are uncommon. Nelson Severinghouse, Jr., President of Franklin Limestone Company, estimates that fewer than 5 percent of the limestone outcrops in North America are suitable for filler and coating applications. In addition, the remote locations of many deposits relative to consuming centers, further limits the number of economically exploitable deposits.

Calcium carbonate used as fillers and extenders must be white (high brightness), consist of equidimensional calcite crystals, and be free of accessory minerals such as pyrite, quartz, feldspar, graphite, and tremolite. Marbles formed by regional metamorphism such as the Sylacauga Marble in Alabama and the Grenville marbles of eastern Ontario contain deposits of white, high purity calcite suitable for use as mineral fillers and pigments.

The deposits of marble in western North America were generally formed by contact metamorphism of carbonate rocks intruded by granitic rocks. The deposits being mined by Pfizer, Inc. and Pluess-Stauffer (OMYA) near Lucerne Valley in southern California occur in large roof pendants of metamorphosed limestone, dolomite, and quartzite. The mineral tremolite is an undesirable accessory mineral in these deposits, and selective mining is used to avoid areas of the pit containing tremolite. White marble deposits being mined in Arizona are chiefly Mississippian Escabrosa Limestone marblized by contact metamorphism with Laramide intrusive rocks.

The principal markets for the ground calcium carbonate products are fillers and extenders, plaster, stucco, feed additives, architectural aggregate, roofing granules, and ground cover. Pfizer Specialty Minerals, one of the two operations in Arizona, produces fine-ground calcium carbonate products which can be used for plastic filling and joint compounds. Georgia Marble, the other producer, is building a plant that will also produce fine-ground calcium carbonate. Figure 1 shows the locations of the deposits described in this report.

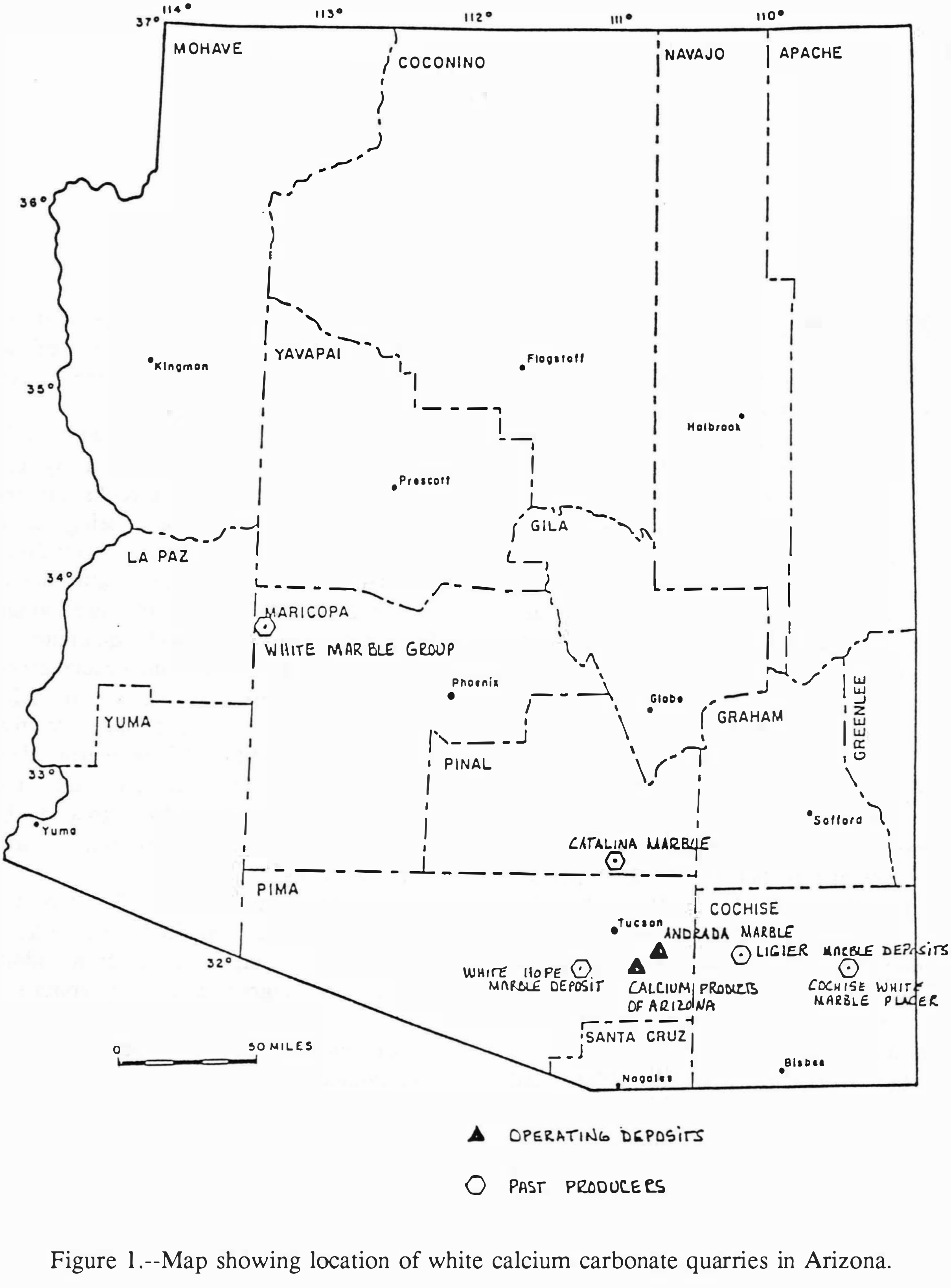

Figure 1.--Map showing location of white calcium carbonate quarries in Arizona.

WHITE CALCIUM CARBONATE PRODUCERS IN ARIZONA

Present production

Georgia Marble Company of Arizona (formerly Andrada Marble Company) -- quarry near Andrada at north end of Santa Rita Mountains. In 1959 David C. Hartley, an engineer in charge of the stripping operations for Isbell Construction Company at the Duval Corporation Esperanza Copper Mine, realized that his employment would terminate when the stripping was completed. He saw that crushed marble was being shipped into the Tucson area from the Ligier Marble Company at Dragoon, Arizona, the San Francisco Marble Company north of Tucson (now Catalina Marble Company), and producers in California. He negotiated a materials purchase contract with Tucson Title and Trust Company, trustee of the Andrada Ranch, to mine marble from a deposit on the Andrada Ranch.

His company, Helvetia Limestone, produced several sizes of coarse marble products in a makeshift plant located at the quarry. Most of the products were sold to decorative stone and roofing companies. By taking advantage of his competitors' higher transportation costs, he was able to undersell his competitors and enlarge his market share. By 1961 one of his competitors, the San Francisco Marble Company, was closed down and by 1962 Mr. Hartley had expanded the capacity of his plant to about 5,000 tons per year. Clearly the residential construction boom in Tucson between 1959 and 1963 helped to expand his sales.

In 1964 production had increased to over 7000 tons per year as Andrada Marble Company continued to take market share away from Dragoon Marble Quarries, Inc., the purchaser of the Ligier Marble Company. Andrada now produced both bagged and bulk products in seven mesh sizes. In another boost to sales, Arizona Feeds began purchasing marble fines for use as animal feed supplements. By 1965 both Sierrita Marble Products (see White Hope marble deposit) and Dragoon Marble Quarries had closed, leaving Andrada Marble Company as the only producer in Arizona.

Mr. Hartley moved the crushing and screening plant to its present location on Drexel Road in Tucson. This move made his crushed and ground marble products more easily accessible to distributors in the Tucson and Phoenix area. Both to secure the existing marble reserves and to increase the reserve, Mr. Hartley purchased the 80 acre Andrada Ranch quarry site from Horizon Corporation. He acquired Arizona State Mineral Leases which cover the extensions of the deposit and purchased fee land to the west of the quarry to prevent urbanization of the area surrounding the quarry site.

Over the past three decades, Andrada Marble Company has continued to hold onto its market share. Since 1959 two operations have started and closed at the Ligier Marble deposit at Dragoon, Arizona; another at the White Marble Group near Wenden operated between 1962 and 1976; Catalina Marble Company began production in 1971; and Calcium Products of Arizona began in 1986.

A combination of four factors has made Andrada Marble Company the lowest cost producer in the state. First, the marble reserves being mined are on fee land owned by David Hartley, and except for the severance tax paid by all producers, no other royalty payments must be made to the State of Arizona. Second, the deposit being mined is a section of marblized Escabrosa Limestone at least 300 ft thick with extensions along strike and down dip. Third, Andrada has only nine employees, including the owner, most of whom have worked at the operation for over 15 years. Fourth, Andrada is a dependable supplier which sells its screened marble products through a large distributor network.

Andrada Marble Company operates a quarry which is about 1,000 ft long, 800 ft wide, and 200 ft deep. The pit exposes a bed of marblized Escabrosa Limestone that is at least 300 ft thick. The deposit was not explored by drilling prior to mining. The marble bed extends out of the quarry along strike and down dip. The Escabrosa is cut by numerous fractures and faults that, near the surface, produce stained and off-color marble. Below the weathered zone the marble is a uniform white color, although there are some zones of gray limestone that are removed during the mining and loading operations. The marble reserves are adequate in the quarry area to sustain the present rate of production for at least 20 years. There are extensive undeveloped reserves on the adjoining Arizona State Mineral Leases.

The marble is hauled 19 mi to the crushing and screening plant on Drexel Road in Tucson. All but the last 1.5 mi into the quarry is paved road. The marble is hauled to the plant in a 20-ton semitrailer owned by Andrada Marble Company. When additional trucks are needed, Bob's Material Supply, one of the marble products distributors, hauls the additional tonnage under contract with Andrada.

The crushing and screening plant operates satisfactorily, though it has been constructed of used equipment. There is no dust control or suppression equipment other than a water spray over the primary crusher. The fine fractions are stored in a shed and two adjoining wrecked railroad box cars with the ends cut out of them. The coarser mesh sizes are stockpiled around the plant along with the bagged products.

Andrada Marble Company sells about 30,000 to 36,000 tons of screened calcium carbonate products per year. About 35 percent of the products are sold in bulk and 65 percent in 80 and 100 lb bags. As the marble products presently have no trade name, empty bags, constituting surplus or overruns of bags printed for other products, are purchased from bag companies. These bags sell for $0.15 each as compared to custom printed bags that sell for $0.35 each. Thus, the bagged marble products are sold in bags with printed labels as diverse as Union Carbide Polyethylene or Arizona Feed Rolled Oats. This is an example of one of the many ways that Mr. Hartley has reduced costs.

Andrada Marble Company sells the following screened products:

50	"Dust"	-27 mesh
16	"sand"	-10 +27 mesh
1/8 in.	" 0 "	3/8 in.
1/2 in.		
5/8 in.		
7/8 in.		
1 1/2 in.		
+3 in.		

Feed grade is 25 percent "16" and 75 percent "50". Swimming pool stucco uses a blend of "16" and "50" that is mixed according to the customer's specifications.

In summary, Andrada Marble Company is the largest producer of screen grades of calcium carbonate products in Arizona. The company has operated continuously for nearly 30 years. It is a low cost producer, has an extensive marble reserve on fee land and sells through a large distributor network. Urbanization could ultimately restrict mining activities at the quarry. Andrada Marble Company was purchased by Georgia Marble Company in 1991, which is constructing a new processing plant at the quarry site.

Pfizer Specialty Minerals (formerly Calcium Products of Arizona) -- quarry near Helvetia west of Santa Rita Mountains. A deposit of marblized high-calcium Escabrosa Limestone on the west side of the Santa Rita Mountains about 25 mi south of Tucson was mined by Homestake Production Company between 1972 and 1975. The marble was calcined into quicklime and used to adjust the pH of the feed in the copper flotation circuits at the mills of the Anamax Mining Company and the Duval

Corporation in the Twin Buttes mining district. The Homestake Production Company shut down when increases in the cost of natural gas made their quicklime uncompetitive with that produced by the Paul Lime Company (east of Bisbee) whose kilns could burn natural gas, fuel oil, petroleum coke, or coal.

Robert Knox owner of Jenott Mining, Inc., a small decorative rock business in Colorado Springs, Colorado formed a Limited Partnership (Calcium Products of Arizona) to produce screened and ground calcium carbonate products. They acquired the property on the west side of the Santa Ritas that had been mined by Homestake Production Company. On December 31, 1986 the agreements were finalized and in June of 1987 all the permits needed to start up the operation had been obtained.

A small portable crushing and screening plant was moved down to the site and set up on the former location of the Homestake Production Company lime plant. The plant can produce coarse screen grades of marble used for roofing gravel and ground cover. The partnership moved an airswept Raymond roller mill to the property, purchased from MI Drilling Fluids barite operation near Battle Mountain, Nevada. In 1990 the Raymond roller mill began producing fine-ground calcium carbonate products which were sold to Murco Wall Products in Buckeye, Arizona.

The marble deposit is extensive. The quarry is developed in a gently dipping, but faulted and fractured bed of marblized Escabrosa Limestone that is 300 to 500 ft thick. Drilling by the Paul Lime Company in about 1961 and later by the Anaconda Company, who was exploring for copper, blocked out 116,000,000 tons of high-calcium high-brightness marble. Conversations with the consulting geologist at Paul Lime Company indicated that there are zones of disseminated pyrite and other sulfide minerals in the marble. Pfizer Specialty Minerals is doing additional drilling to block out reserves in several quarry sites.

The deposit is covered by unpatented mining claims first located by Sherwood B. Owens of Tucson. No information is available regarding the terms and conditions of the original claims agreement. Initial production, however, was permitted under a Materials Purchase Agreement with the U.S. Forest Service, which imposes a royalty payment to the Federal Government of $0.85 per ton. The Forest Service classifies coarse crushed marble used as ground cover, roofing granules, or architectural aggregate as a salable mineral. The production of fine-ground marble products will not be subject to the Materials Purchase Agreement.

The small portable crushing plant initially operated at the deposit had no dust control equipment. Therefore, under an agreement reached with the Pima County Air Quality Control District, the jaw crusher could not be operated when the secondary crusher and screening equipment were in operation. This caused serious operating problems because the output of the jaw crusher had to be stockpiled and then fed into the secondary crusher and screens with a front end loader.

Initially the sales of crushed marble did not meet the projections made in the business plan, although production did reduce the market share held by Andrada Marble Company. The principal reason was that the plant is located 25 mi south of Tucson and the final 15 mi of the access road is not paved. Consequently, the crushed marble products were sold at a significant discount to compensate for the additional transportation costs. This meant that their crushed and screened bulk marble products sold for only $11.00 per ton FOB. Bagged products were not available.

In an attempt to increase sales revenues Calcium Products of Arizona began crushing a brown iron stained (Bolsa?) quartzite that crops out west of the marble deposit. In fact, in 1989 sales of the brown quartzite, which was sold for both roofing granules and ground cover, exceeded those of the white marble. Unfortunately, the dust from the crushing operation contaminated the crushed marble stockpiles.

When Calcium Products of Arizona began operations in mid-1987 it was the newest and smallest producer of calcium carbonate products in Arizona, although it controlled a large marble reserve. Initially the company operated a small portable crushing and screening plant which produced only coarse screen grades suitable for roof granules and ground cover. The fine grinding facility became operational in 1990. Most of the fine-ground calcium carbonate production was sold to Murco Wall Products in Buckeye, Arizona. In December 1991 Pfizer Specialty Minerals purchased Calcium Products of Arizona. Pfizer has started a $3 million exploration and modernization project as part of an intensified program for expanding limestone sales in the southwest.

Past production

Catalina Marble Company. A deposit of marblized Permian age Concha Limestone on the east slope of the Tortolita Mountains, 6 mi west of the town of Catalina, has been mined most recently by the Catalina Marble Company. Originally, San Francisco Marble Company operated this deposit in 1958. A small crushing and screening plant produced marble roof granules. The quarry and plant, which operated on an intermittent basis, was owned by Joe F. Ramirez, owner of Old Pueblo Roofing Company in Tucson.

In 1959 Baldo Hernandez purchased the quarry and the crushing and screening plant. The quarry and plant operated intermittently for about a year, and in 1960 the plant was sold to Crystal White Rock Company who moved it to 1140 N. Anita in Tucson. Baldo Hernandez supplied mine run marble from the quarry to Crystal White Rock Company. In 1961 Crystal White Rock Company shut down their operation and all mining at the quarry stopped.

In 1971 Mountain Gravel and Construction Incorporated, based in Delores, Colorado, formed Catalina Marble Company and acquired the six Arizona State Mineral Leases from the previous owners. Production of coarse screen grades of white marble products began in 1972. The quarry and plant operated intermittently for many years. Although production continued to increase, the operation was never particularly profitable. In 1987 Mountain Gravel and Construction sold the operation to Darrell Goode, the property manager. The operation shut down in 1991.

The quarry developed a 60 ft wide marble horizon for about 300 ft along strike. The marble horizon continues for several thousand feet to the west of the quarry site and for an unknown distance to the east. It dips steeply to the south. The deposit was not explored by drilling. Nevertheless, the continuous marble exposures along strike certainly suggest that sufficient reserves are available for several years.

Small fractures and faults cut and locally displace the marble horizon. Near the surface, the marble is stained adjacent to the fractures. Stratigraphically above and overlying the marble is a dense black silicified limestone which must be stripped off the marble horizon.

The marble from this deposit has a higher brightness than the marblized Escabrosa Limestone that has been produced at Andrada Marble Company (now Georgia Marble Company) and Calcium Products of Arizona (now Pfizer Specialty Minerals). There was no pyrite or other sulfides in the marble horizon. Areas of off-colored stone were sorted out in the quarry.

The crushing and screening plant was carefully laid out and well maintained. In addition the plant site and stock piles were clean and free of dust. The bagged and palletized screen-grade marble products were stored in an area below the plant site.

The screen-grade marble product used in swimming pool plaster was sold under the trade name Catalina White. This was the highest brightness plaster sand available in

Arizona. All of the tramp iron was removed from the product after the final screening with an electromagnet which eliminated the possibility of the plaster becoming stained after a swimming pool has been filled with water. Catalina White sold for $1.85 per 100 lb sack ($37 per ton).

Much of the oversize marble from the quarry was sorted by hand, placed in screen cylinders on a pallet, and sold for decorative stone. This was the most profitable product sold by Catalina Marble Company. A pallet that weighed about a ton sold for $75.

In 1989 production at Catalina Marble Company was about 20,000 tons of screen-grade marble products a year. The operation had four employees including Mr. Goode, who operated the quarry and the crushing and screening plant. Because the operation was in Pinal County it was not subject to the air quality standards enforced in Pima County.

In 1989 Catalina Marble Company was perhaps the best managed producer of screen-grade calcium carbonate products. Nevertheless, all of the production came from the State of Arizona Mineral Leases which were subject to a royalty of 5 percent of the gross sales less processing, transportation costs, and taxes. The Kadish decision, which changed the royalty on mineral production from a net to a gross proceeds basis on State of Arizona Mineral Leases, undoubtedly had a impact on the profitability of Catalina Marble Company.

In summary Catalina Marble Company produced about 20,000 tons per year of high-brightness screen-grade calcium carbonate. Their Catalina White product which was used in pool plasters was the highest brightness, iron free product available in Arizona, and commanded a premium price. The company operated the quarry and processing plant from 1971 to 1991. The marble reserve on Arizona State Mineral Leases appeared to be adequate to supply the operation at its 1989 level of production for at least 20 years. The plant location, over 20 miles north of Tucson, is closer to the Phoenix market than that of either Georgia Marble or Pfizer.

The Ligier marble deposits. Leon Remy Ligier, a French stone mason who moved to Phoenix sometime prior to 1900, began producing marble for statues and dimension stone from a quarry in a deposit of marblized Escabrosa Limestone on the east side of the Chiricahua Mountains about 20 mi south of Bowie, Arizona. He sold this quarry and in 1909 staked claims on a deposit in the Dragoon Mountains south of the town of Dragoon. Because of protracted litigation and World War II, production did not begin until 1946. Three of L.R. Ligier's sons formed the Ligier Marble Company and began quarrying dimension stone from a deposit of marblized Permian and Pennsylvanian Earp Limestone and Mississippian Escabrosa Limestone.

Marble exhibiting a wide variety of textures and colors was produced from three quarries. Five types of dimension stone and statuary marble were sold. These included Navajo Black and Gold, Breche Saguaro, Apache Gold, Geronimo, and Naretina. In 1950 the Ligier Marble Company became the first producer of terrazzo, roof granules, and decorative stone in Arizona. Soon afterward crushed products supplanted the dimension stone in tonnage and value.

In 1962 the Ligier Marble Company was purchased by Charles C. Lewis Company, a steel products distribution firm based in Springfield, Massachusetts. The new company, known as Dragoon Marble Quarries Incorporated, expanded production of both crushed marble products and dimension stone. The operation was closed about 1965. The plant and equipment were sold and the claims were returned to the Ligiers. Reasons for the closure included a high corporate overhead, but perhaps more important was the competition from newly established producers in the Tucson area who were closer to both the Phoenix and Tucson markets. Hoped for sales into the California markets did not materialize because the producers of crushed marble in the Lucerne Valley and Victorville area in southern California were over 400 miles nearer to the large Los Angeles markets.

In 1967 Thompson, Weinman, and Company (which was recently acquired by English China Clays from Cyprus Industrial Minerals) explored the deposit. Ernest Reade, Jr., the geologist in charge of the exploration program, concluded that the marble would need beneficiation to produce a high-brightness product for filler and extender applications.

About 1978 a group of investors and a local rancher, Rush Dezonia, constructed a crushing and bagging plant on the west side of the town of Dragoon. This plant operated for only a short time. The products were good quality and available in several mesh sizes and colors, however, management had made no provision for the cost of marketing, sales, and distribution. They also failed to consider the competition from the Tucson producers. As a result they were unable to sell the product and eventually shut down. In 1985 Dragoon Marble Corporation, which was controlled by Red Mountain Mining Company based in Tempe, Arizona, constructed a new crushing and screening plant at the site of the original Ligier Marble Company plant about 5 mi east of Dragoon. The quarry was reopened and production of crushed marble was begun. After operating only a few months the operation shut down and the vehicles and equipment were sold. In this case the company did not have the financial resources to get through the startup period even though it had a good distribution network in the Phoenix metropolitan area.

In 1987 another investment group in Tucson attempted to put the Ligier property into production, but the U.S. Forest Service refused to allow production from the property except under a Materials Purchase Contract. The U.S. Forest Service has classified crushed marble used as architectural aggregate, terrazzo, or ground cover to be a common mineral material. Further, the Forest Service could refuse to issue a Materials Purchase Contract because of the visual impact of quarries as viewed from Interstate 10 at Texas Canyon.

Other calcium products were also produced from the Ligier marble deposits. Paul Lime Company, a lime producer located at Paul Spur 20 miles east of Bisbee, Arizona, mined a deposit of marblized Escabrosa Limestone that is an extension of the Ligier deposit. The marble was calcined at their plant at Paul Spur and sold as a high plasticity lime for use in mortars. Paul Lime Company also supplied the Apache Powder Company at Benson with marble containing 99.2 percent $CaCO_3$.

Paul Lime Company attempted to acquire another deposit of marble in southern Arizona which would make a high plasticity lime product. At least two other deposits were drilled. One of the deposits on the west side of the Santa Rita Mountains is now being mined by Pfizer Specialty Minerals. The other is the White Hope property on the west side of the Sierrita Mountains.

Paul Lime Company discontinued production of high plasticity lime in the mid 1960's. The claims were dropped and relocated by Joe Tapia of Dragoon.

In summary, the Ligier marble deposit has a recoverable reserve of 1.7 million tons based on the drilling done by Thompson, Weinman and Company. The crude brightness of this reserve is 91 which meets the specifications for applications such as joint cement, stuccos, and plasters. Wet beneficiation could make a fine-ground product suitable for most filler-extender applications in plastics and paints.

Because the Ligier marble deposit is nearly 70 mi east of Tucson, additional transportation costs currently represent a significant competitive disadvantage with the producers in the Tucson area. Nevertheless, this cost disadvantage may disappear. First, because of the increasingly stringent air quality regulations in Pima County, and second, because urbanization is beginning to encroach upon the producers in the Tucson area. The Ligier Marble deposit is located near both the main line of the Southern Pacific Railroad and Interstate 10 and well outside of the Pima County air quality control district. This is a deposit that may be mined when the cost of air pollution control equipment, or restrictions imposed by urbanization in the Tucson area offset the transportation cost advantage of the producers in Pima County.

The White Hope marble deposit. In 1958 Brittain-Hendrickson Mining Company located seven 20-acre State Mineral Leases and four unpatented claims on federal land that covered a deposit of marble on the southwest side of the Sierrita Mountains. Applications were filed for six additional 20 acre leases and three more unpatented claims were staked to insure complete coverage of the deposit.

The deposit appears to be an unnamed marblized Paleozoic limestone and underlying dolomitic limestone of the Martin Formation. Contact metamorphism has obliterated sedimentary structures and fossils making identification of the formational units difficult. In 1961 the Paul Lime Company evaluated the White Hope Deposit as a source of high-purity calcium lime used in high-plasticity lime. The exploration project, which included a seven hole drilling program, blocked out 4 to 5 million tons of marblized limestone with a high calcium content.

Brittain-Hendrickson Mining Company operated the quarry from 1959 to about 1965. All of the production was sold to Sierrita Marble Products, who operated a crushing, screening, and bagging plant at Three Points, 25 mi west of Tucson. The crushed marble products included roofing granules, ground cover, stucco and pool plaster sand, and animal-feed supplements. There is no published information available that indicates why Sierrita Marble Products closed their operation around 1965. However, our files indicate that the partial closure of Hughes Aircraft Plant in Tucson in 1965 severely depressed the market for new homes. This resulted in the bankruptcy of Lusk Corporation, the largest home builder in Tucson and one of the major consumers of roofing granules.

An additional factor in the Sierrita closing may have been that the marble contained pyrite that oxidized when exposed to weather, staining the roofing granules and ground cover. And finally, the remote location of both the quarry and processing plant from the Tucson and Phoenix markets made their products uncompetitive. In contrast, the Andrada Marble Company (now Georgia Marble Company) had their plant in an industrial park on the southeast side of Tucson, less than 20 mi from their quarry.

In summary, the White Hope Marble Deposit has a reserve of 4 to 5 million tons based on drilling done by Paul Lime Company. Though no crude brightness measurements were done, the description of the deposit indicates that the marble is very white. It appears that wet beneficiation could remove the pyrite and produce a product suitable for most filler-extender applications.

However, the remote location of the deposit, 50 miles southwest of Tucson, means that the marble produced from the deposit would have a significantly higher cost than that of producers in the Tucson area. Further, because the deposit is in Pima county, the same stringent emissions standards with which the other producers must comply would be imposed on this operation. Thus, it is not likely that the deposit will become a producer again in the near future.

The White Marble group. Marble production began in 1962 from deposits of either Escabrosa or Kaibab marblized limestone, in the Harquahala Mountains west of the Maricopa - La Paz county line. The Arizona Department of Mines and Mineral Resources files list several individuals and companies who operated the deposits. U.S. Marble Company operated the quarries from

1962 to 1968. Between 1969 and 1970, Fisher Enterprises operated the quarries, and a crushing and screening plant on the southside of U.S. Highway 60 about 5 mi east of Wenden, Arizona. In 1971 Fisher Enterprises became The Superior Companies.

Certainly the largest producer was The Superior Companies and its predecessor company, Fisher Enterprises. The Superior Companies, an industrial minerals producer, appears to have acquired the property from U.S. Marble in 1971 and began production of crushed marble products used as roofing granules, ground cover, and plaster and stucco sand.

According to our file data the operation closed down in 1976 when it became unprofitable. The specific causes of the closure are not known. However, an important factor was probably that the processing plant was 100 mi from Phoenix. Significantly, this is about the same distance as from Phoenix to the Catalina Marble Company 20 miles north of Tucson; and it is only about 120 miles from Phoenix to the Georgia Marble Company plant (now Georgia Marble Company) in Tucson. Both of these companies are low-cost producers of high-brightness and high-calcium marble (although Catalina Marble Company is presently shut down). Finally, it appears that U.S. Marble, the previous owner, may have held a production royalty that, combined with the production costs, made the marble products uncompetitive. In any case the marble products sold by The Superior Companies were not competitive with those sold by the producers in the Tucson area.

Since The Superior Companies closed down the operation, several other companies and individuals have either explored or attempted to place the property into production. In 1979 Sun Landscaping and Supply operated the quarries for a short period of time. In 1982 Vermont Stone and Minerals Ltd., based in Landgrove, Vermont, explored the deposit with several drill holes. Finally, in 1986 Murco Wall Products evaluated the deposit as a potential source of fine-ground calcium carbonate used in joint cement.

In summary, the White Marble Group produced crushed marble products used as roofing granules, ground cover, and plaster and stucco sand from 1968 to 1976. Attempts to operate the deposit since The Superior Companies shut down have not been successful. It appears that the marble products produced from the deposit were uncompetitive with products available from the two producers in the Tucson area. The deposit does not have significant transportation advantage over the Tucson producers. Therefore, the marble products had to be at least equal both in quality and price to compete effectively with the Andrada Marble Company and Catalina Marble Company products.

Cochise White Marble placer. The Cochise White Marble placer, the first productive marble deposit in Arizona, was staked by Leon Remy Ligier. He sold the placer claim sometime between 1900 and 1909. The claim covered 143.8 acres and was patented in 1912.

Marble dimension stone and blocks of statuary marble remain at the quarry site south of Bowie on the east side of the Chiricahua Mountains. No crushed rock was produced from this deposit. The deposit is probably marblized Escabrosa Limestone and appears to be extensive. It is, however, remote from any major population centers.

In summary, the Cochise White Marble placer could be a major deposit of high-brightness marble. However, the deposit is located too far from the Phoenix, Tucson, or El Paso markets to be competitive in the ground calcium carbonate markets at this time. The Tucson and Phoenix markets are supplied by producers in the Tucson area. El Paso is supplied by Texas Agricultural Aggregates, which operate the White Marble Mine near Van Horn, Texas.

Nevertheless, the Cochise White Marble placer has three potential economic advantages. First, it is a large deposit of white marble. Second, it is located on a patented mining claim, which means that the deposit could be brought into production without all of the permitting required by the U.S. Forest Service and without negotiating a Materials Purchase Contract. Third, the increasingly stringent air quality regulations in Pima County, and the urbanization that is beginning to encroach on Tucson area quarries may increase production costs in the future and cause some of the operations to shut down. Therefore, both the Chiricahua White Marble placer and the Ligier Marble deposit at Dragoon may be potentially valuable sources of high-brightness calcium carbonate.

GEOLOGY OF THE WHITE CLIFFS DIATOMITE DEPOSIT AND ARAVAIPA CREEK GYPSUM DEPOSIT, LOWER SAN PEDRO VALLEY, ARIZONA

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ABSTRACT

The geology of the White Cliffs diatomite and the Aravaipa Creek gypsum deposits is summarized. Regional stratigraphy and structure of the Upper Miocene and Pliocene Quiburis Formation, which hosts the deposits, are described. The geology of the White Cliffs deposit is described in detail, while only preliminary geologic information is presented for the Aravaipa Creek gypsum deposit. The report provides a framework for understanding the nonmetallic mineral resource potential of the lower San Pedro Valley basin-fill sediments.

INTRODUCTION

This report summarizes the geology of two nonmetallic mineral deposits in Arizona: (1) the White Cliffs diatomite deposit and (2) the Aravaipa Creek gypsum deposit. These two deposits are located in southeastern Arizona in the lower San Pedro Valley (fig. 1). The Aravaipa Creek deposit currently supplies gypsum to Arizona's contruction and agricultural industries, while the White Cliffs deposit is currently idle.

This report focuses mainly on the stratigraphy and structure of the upper Miocene and Pliocene Quiburis Formation, which hosts the gypsum and diatomite, with an emphasis on the more completely studied White Cliffs deposit. The Aravaipa Creek gypsum deposit is not as well understood, and the geologic information provided is considered very preliminary in nature. It is hoped this report will provide the groundwork for future geologic work geared toward better definition of the nonmetallic mineral resource potential of the San Pedro Valley basin-fill sediments.

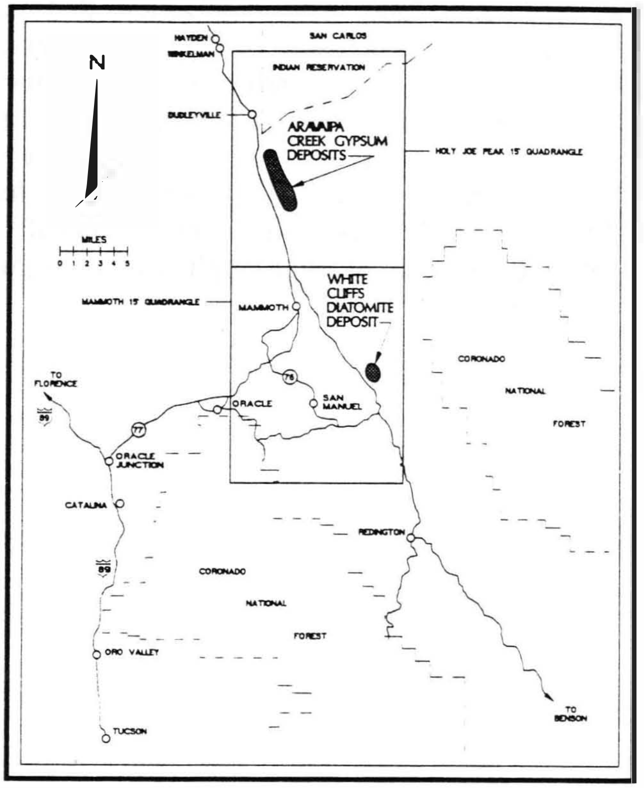

Figure 1.--Location map of the White Cliffs diatomite deposit and the Aravaipa Creek gypsum deposits.

REGIONAL GEOLOGIC SETTING

The general geology of the Holy Joe Peak and the Mammoth 15' quadrangles is shown in figure 2. The bedrock geology was compiled from Dickinson (1987) and the basin-fill geology was compiled from Hardas (1966), Krieger (1968a,b and 1974), Utley (1980), Pearthree and others (1988), Shenk (1990), and personal reconnaissance mapping. For a detailed discussion of the bedrock, the reader is referred to Dickinson (1987 and 1991). The undifferentiated basin-fill sediments (TQs)

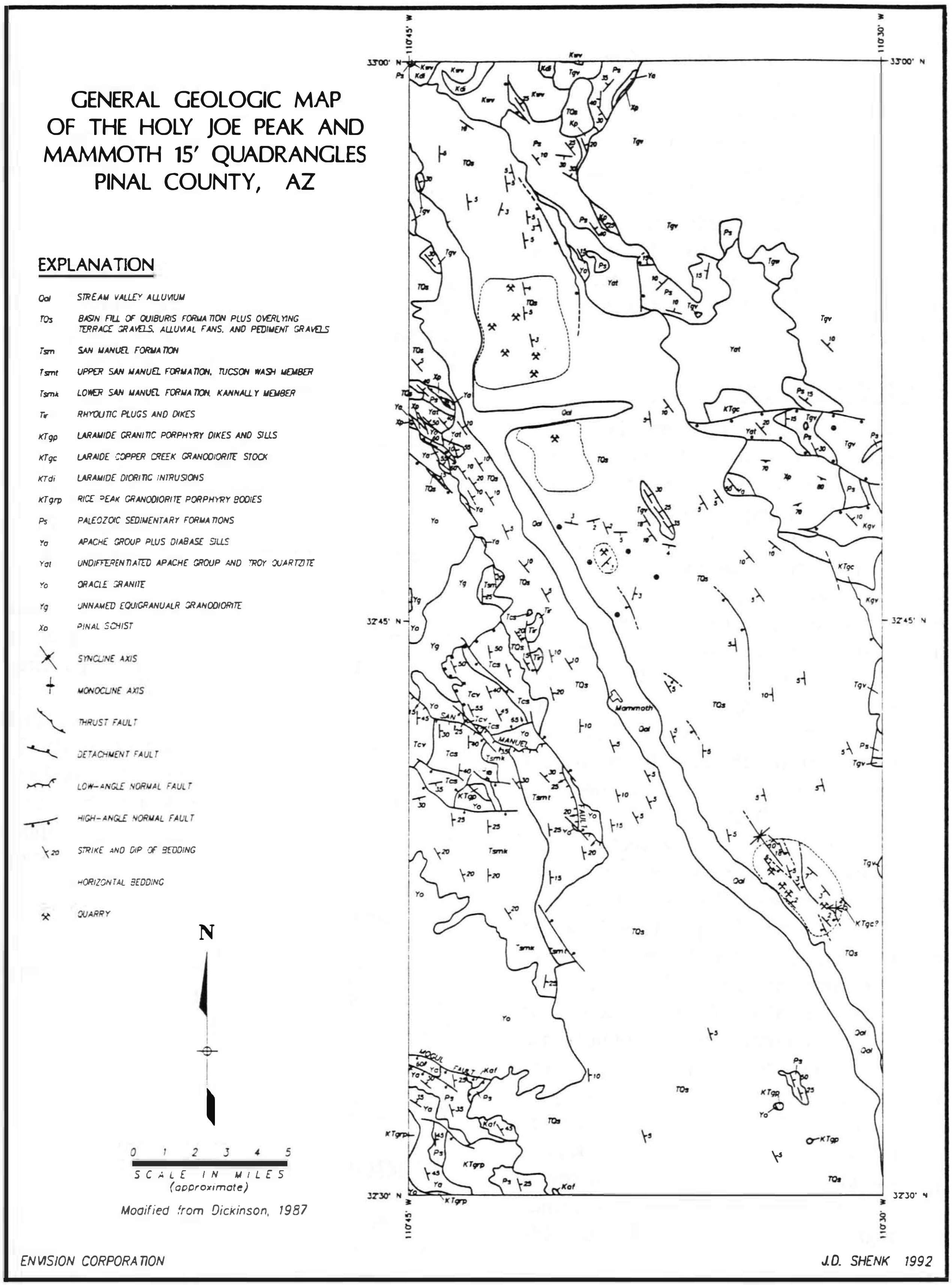

Figure 2.--General geologic map of the Holy Joe Peak and Mammoth 15' quadrangles, Pinal County, Arizona. Compiled from Hardas (1966), Krieger (1968a,b; 1974), Utley (1980), Dickinson (1987), Pearthree and others (1988), Shenk (1990), and personal reconnaissance mapping.

shown on figure 2 are composed of lacustrine and laterally equivalent alluvial fan sediments of the upper Miocene and Pliocene Quiburis Formation and unnamed Pliocene and Pleistocene terrace gravels, pediment gravels, and alluvial fans. Dissecting the undifferentiated basin-fill sediments are active Holocene stream channels (Qal). Details of the basin-fill stratigraphy and structure, with emphasis on the Quiburis Formation, are discussed below.

Basin-Fill Stratigraphy

Stratigraphically, the Quiburis Formation consists predominantly of two facies: 1) a fine-grained, lacustrine facies composed of thinly bedded to laminated, gypsiferous to calcareous silt with interbedded massive gypsum, diatomaceous marls, diatomite, chert, and volcanic ash and 2) a laterally equivalent alluvial fan facies composed of bedded to massive, sandy to bouldery conglomerate (Heindl, 1963; Agenbroad, 1967; Utley, 1980; Shenk, 1990). Agenbroad (1967) informally named the fine-grained lacustrine facies the Redington member and the laterally equivalent coarse-grained alluvial fan facies the Tres Alamos member. Both the White Cliffs diatomite deposit and the Aravaipa Creek gypsum deposits are hosted in the fine-grained lacustrine facies (Krieger, 1968a, 1968b, 1974; Shenk, 1990). Using well-log data and surface exposures, Agenbroad (1967) inferred a total thickness of approximately 520 m for the Redington member along the valley axis. At the White Cliffs diatomite deposit, radiometric age dates of interbedded volcanic ash layers range between 5.35 and 6.43 Ma (late Miocene), the vertebrate fossil assemblage is late Hemphillian (late Miocene and Pliocene), and paleomagnetic studies place the formation in magnetic chron 5 (late Miocene) (Scarborough, 1975; Lindsay, 1984; Reynolds and others, 1986). Shenk (1990) mapped the geology of the White Cliffs deposit and showed that part of the Quiburis probably extends well into the Pliocene.

Unconformably overlying the Quiburis Formation are unnamed terrace gravels, pediment gravels, and alluvial fans. These gravels are undifferentiated on figure 2, however, Pearthree and others (1988), using aerial photographs and reconnaissance field-checking, mapped and dated these younger gravels at a scale of 1:250,000 based on their geomorphic characteristics and soil development. They recognized three broadly defined units ranging in age from: (1) 0 to 10 ka (Qal), (2) 10 ka to 790 ka, and (3) 790 ka to greater than 2,000 ka.

Basin-Fill Structure

Structurally, the Quiburis Formation is regionally disrupted by a northwest-trending zone of high-angle normal faults and synclinal folds approximately 1.5 to 3.0 km east of the present San Pedro River (fig. 2). Limited reconnaissance mapping has not defined this zone in the vicinity of the Aravaipa Creek gypsum deposits, but the location of the deposits immediately north of and on strike with the zone suggests that future detailed mapping may yet define it here. A second zone of structural disruption, marked by high-angle normal faults and a series of northeast-dipping inliers of Galiuro volcanics, is located approximately 5 km east of and roughly parallel to the first zone. Both of these structural zones parallel the inferred regional breakaway zone mapped by Dickinson (1991) midway between the volcanic inliers and the main mass of the Galiuro Mountains (Dickinson, 1991, fig. 34).

WHITE CLIFFS DIATOMITE DEPOSIT

Diatomite Overview

Diatomite is a sedimentary rock consisting mainly of the siliceous remains of diatoms, single-celled organisms related to the algae (Kadey, 1983; Burnett, 1991). The term is reserved for those occurrences with potential commercial value (Kadey, 1983; Bates and

Jackson, 1987), however, in practice, the economic aspect of the definition is commonly overlooked. In addition, processed final products are sometimes referred to as diatomite. To avoid definition confusion, Shenk (1990) suggested the term "diatomite" be used for describing the rock in the unprocessed, crude ore form and that the term "diatomaceous earth" (or DE) be used for processed final products. To further define the term, a proposed diatomite classification scheme is presented in this report using three end-members: calcium carbonate, siliciclastics, and diatoms (fig. 3). Diatoms and siliciclastics are both physical particles and are therefore treated equally (25, 50, and 75 percent) along the base of the triangle. Calcium carbonate, however, is typically a chemical sediment and economically tends to be more deleterious to a deposit. Therefore, a different scale (10, 40, 70, and 90 percent) is used for defining the lithologic fields relative to calcium carbonate. The proposed diagram works well both geologically and economically, as most active economic deposits will fall in the defined diatomite or silty diatomite fields. Samples collected from White Cliffs fall in a range between silty diatomite and diatomite to diatomaceous marl.

Tectonically, lacustrine diatomite deposits commonly are located in areas of crustal extension. In addition, they are typically associated with volcanic terrains, and, relative to volcanic rocks, three different varieties of lacustrine diatomite deposits are recognized: 1) volcanic hosted (diatomaceous sediments deposited in craters or maars), 2) volcanic and sediment hosted (diatomaceous sediments interbedded with volcanic flows or tuffs and fluvial or alluvial sediments), and 3) sediment hosted (diatomaceous sediments interbedded with fluvial or alluvial sediments) (Shenk, 1991). Using this scheme, the White Cliffs deposit is classified as a sediment hosted deposit with nearby associated volcanics located in the extensional Basin and Range province.

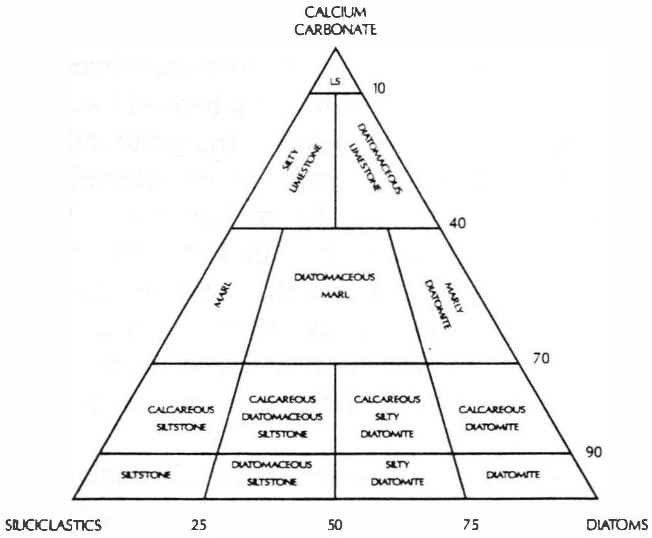

Figure 3.--Proposed diatomite classification scheme.

Local Geology

The general geolgy of the White Cliffs diatomite deposit, simplified from Shenk (1990), is shown in figure 4. Bedrock inliers include a small outcrop of Laramide(?) quartz monzontite (KTgc), tentatively correlated with the Copper Creek granodiorite complex, and a larger outcrop of Galiuro volcanics (Tgv). Basin-fill sediments (TQs) are undifferentiated and consist of gypsiferous to calcareous silt, diatomaceous marls, diatomite, and chert, plus overlying gravels. The basin-fill sediments are dissected by recent stream valley alluvium (Qal). Structural disruptions include several northwest-striking high-angle normal faults, a northwest-trending shallowly folded syncline, and a northeast-trending moderately folded monocline (fig. 4).

Stratigraphy

In the White Cliffs area, Shenk (1990) modified Agenbroad's (1967) Redington member definition and divided the fine-grained facies of the Quiburis Formation into three informal members: (1) the Redington member (Rm), (2) the Gust James member (GJm), and (3) the White Cliffs member (WCm). Two distinctive ash layers, the upper ash (UA) and lower ash (LA), were used as marker beds (fig. 5).

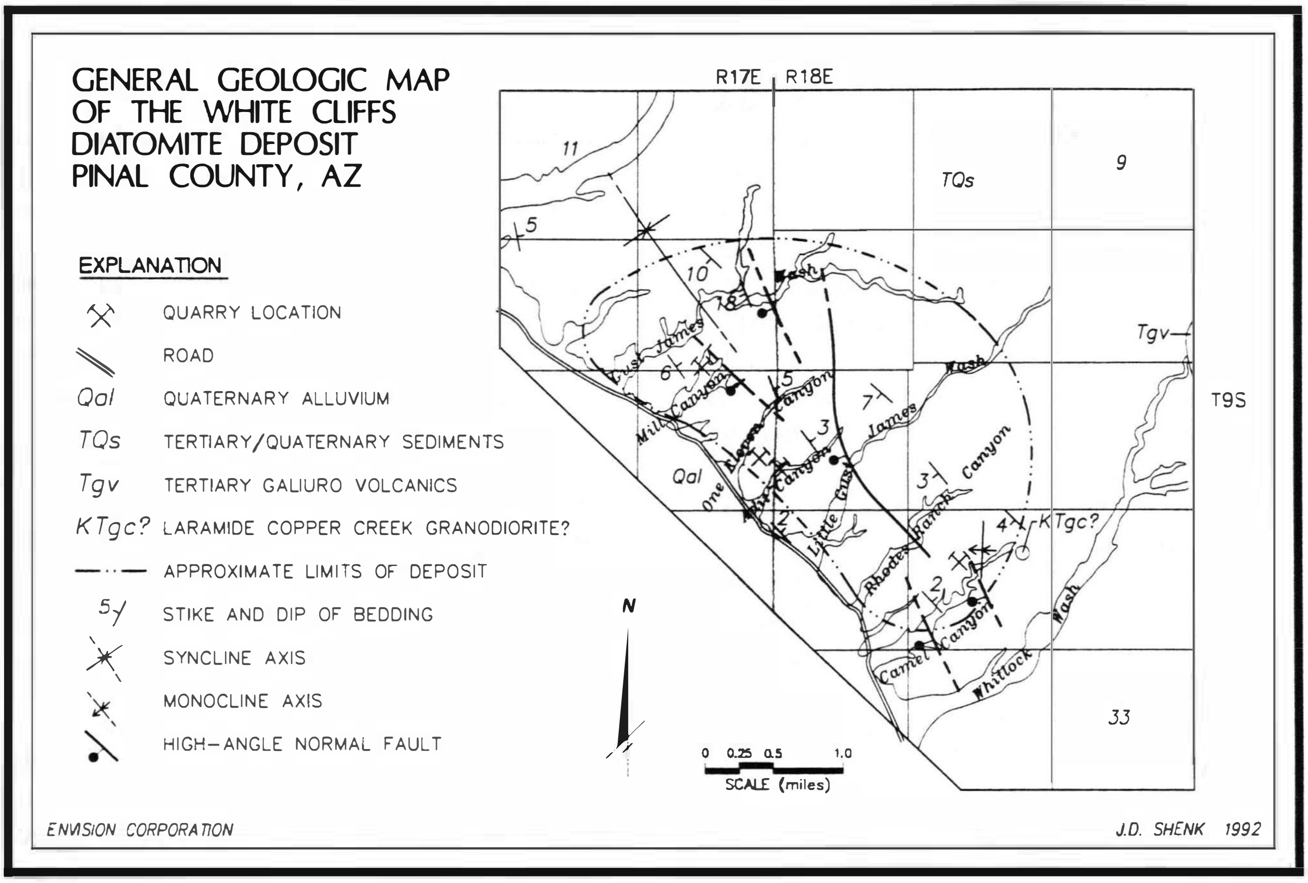

Figure 4.--General geologic map of the White Cliffs diatomite deposit (simplified from Shenk, 1990).

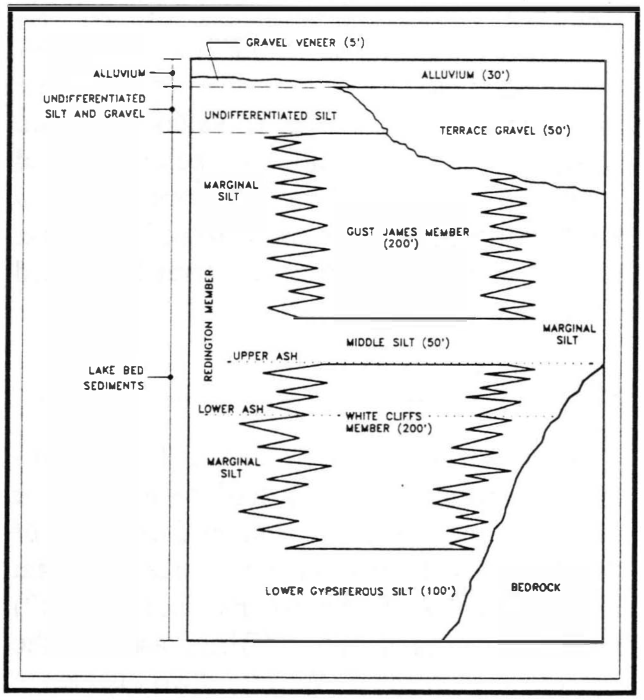

Figure 5.--Stratigraphy of the White Cliffs diatomite deposit (from Schenk, 1990).

The Redington member, as modified by Shenk (1990), overlies, underlies, and interfingers with the White Cliffs member and Gust James member and consists predominantly of laminated silt with minor interbeds of locally crossbedded sand and gravel. Stratigraphically, parts of the Redington member are referred to as marginal silts and the middle silt. The marginal silts and the middle silt that interfinger with, and underlie the Gust James member tend to be calcareous, while the marginal silts which interfinger with and underlie the White Cliffs member tend to be gypsiferous.

The Gust James member ranges in thickness from 0 to more than 60 m and consists of interbedded diatomaceous marl and calcareous silt. The upper contact with Redington member silt and (or) younger terrace and pediment gravels varies from an ill-defined, gradational contact marked by undifferentiated silt and gravel to a sharp erosional unconformity. The lower contact with the areally extensive, interbedded, Redington member middle silt is gradational. The contact between the middle silt and the underlying White Cliffs member is an unconformity and is commonly, but not always, marked by the upper ash marker bed.

The White Cliffs member ranges from 0 to more than 60 m and consists of interbedded silt, diatomaceous marl, diatomite, and locally abundant chert. Note that diatomite and abundant chert are only found in the White Cliffs member. Evidence from drill holes located around the margins of the deposit indicate that interbedded diatomite and chert extend down to approximately the 762-m (2,500-ft) elevation level and that below this elevation interbedded gypsum and chert occur. Where exposed at the northwest end of the deposit, the lower contact between the White Cliffs member and Redington member gypsiferous silt is gradational and is found at approximately the 792-m (2,600-ft) elevation level.

ARAVAIPA CREEK GYPSUM DEPOSIT

Gypsiferous sediments occur throughout the lower San Pedro Valley, with the thickest known deposits occurring on the east side of the San Pedro River in the vicinity of Aravaipa Creek (figs. 1, 2). These deposits cover approximately 46 km^2 and are divided roughly in half by the east-west flowing Aravaipa Creek. Unfortunately, a detailed geological study of the Aravaipa Creek gypsum deposits is not available, and work currently in progress by the present author is limited to a few reconnaissance trips and literature review. Therefore the following summary, compiled from Hardas (1966), Shearer (1988), Eyde and Wilt (1989), and personal knowledge, is very preliminary in nature.

Local Geology

North of Aravaipa Creek, as evidenced by the distribution of quarries and the strike and dip of the bedding (fig. 2), it appears that at least two different stratigraphic horizons of gypsum occur. It is also possible, however, that this is actually one gypsum horizon offset by the regional zone of high-angle normal faulting paralleling the San Pedro River. The beds being mined north of the creek are reported as massive, high grade rock gypsum with clay partings, averaging greater than 90 percent gypsum and ranging in thickness from 9 to 15 m.

South of Aravaipa Creek, the beds being mined are reported as either granular gypsum or surficial gypsite with an average thickness of about 1.5 m. Exploration drilling in 1987, however, defined an indicated resource of 13 million s.t. of near surface, hard rock gypsum ranging from 80 to 90 percent gypsum. Deeper drilling intersected approximately 168 stratigraphic m of interbedded gypsum and clay. Forty individual gypsum beds or units were recognized, ranging in thickness from several cm to more than 3 m. A regional strike and dip of N31°E, 2°SE was determined for these beds from a thin volcanic ash bed recognized in the drill holes. Volcanic ash also outcrops locally in the district and may provide a means for detailed, basinwide stratigraphic correlations.

CONCLUSIONS

This report summarizes the geology of the White Cliffs diatomite deposit and the Aravaipa Creek gypsum deposit. The goal is to provide the groundwork for continued geologic work on the nonmetallic mineral resources of the lower San Pedro Valley basin-fill sediments. The regional stratigraphy and structure of the upper Miocene and Pliocene Quiburis Formation, which hosts the gypsum and diatomite, is described. Locally, the emphasis is on the better understoond White Cliffs diatomite deposit, and only preliminary geologic information is provided on the Aravaipa Creek gypsum deposit.

Future work should concentrate on (1) detailed mapping of the geology of the Aravaipa Creek gypsum deposit, (2) extending the detailed mapping south of White Cliffs diatomite deposit, and (3) using the volcanic ash layers to date and correlate the Quiburis Formation on a regional basis.

REFERENCES CITED

Agenbroad, L.D., 1967, Cenozoic stratigraphy and paleo-hydrology of the Redington-San Manuel area, San Pedro Valley, Arizona: Tucson, University of Arizona, Ph.D. Dissertation, 119 p., plates.

Bates, R.L., and Jackson, J.A., 1987, Glossary of geology: American Geological Institute, Falls Church, Virginia, 3rd ed.

Burnett, J.L., 1991, Diatoms, the forage of the sea: California Geology, vol. 44, no. 4, p. 75-81.

Dickinson, W.R., 1987, General geologic map of Catalina core complex and San Pedro trough: Tucson, Arizona Bureau of Geology and Mineral Technology, Miscellaneous Map Series 87-A, 18 p, 15 plates, scale 1:62,500.

Dickinson, W.R., 1991, Tectonic setting of faulted Tertiary strata associated with the Catalina core complex in southern Arizona: Geological Society of America Special Paper 264, 106 p., 1 plate, scale 1:125,000.

Eyde, T.H., and Wilt, J.C., 1989, Arizona industrial minerals, a growing industry in transition, in Jenney, J.P., and Reynolds, S.J., Geologic evolution of Arizona: Tucson, Arizona Geological Society Digest 17, p. 741-758.

Hardas, A.V., 1966, Stratigraphy of gypsum deposits, south of Winkleman, Pinal County, Arizona: University of Arizona, Tucson, M.S. Thesis, 45 p.

Keith, S.B., 1969, Gypsum and anhydrite, in Mineral and water resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 371-382.

Krieger, M.H., 1968a, Geologic map of the Holy Joe Peak quadrangle, Pinal County, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-669, 4 p., scale 1:24,000.

Krieger, M.H., 1968b, Geologic map of the Saddle Mountain quadrangle, Pinal County, Arizona: U.S. Geological Survey Geological Quadrangle Map GQ-671, 3 p., scale 1:24,000.

Krieger, M.H., 1974, Geologic map of the Winkelman quadrangle, Pinal and Gila Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1106, 8 p., scale 1:24,000.

Pearthree, P.A., McKittrick, M.A., Jackson, G.W., and Demsey, K.A., 1988, Geologic map of Quaternary and Upper Tertiary deposits Tucson 1°x2° quadrangle, Arizona: Tucson, Arizona Geological Survey, Open-File Report 88-21, scale 1:250,000.

Reynolds, S.J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of radiometric age determinations in Arizona: Arizona Bureau of Geology and Mineral Technology, Bulletin 197, 258 p., 2 plates, scale 1:1,000,000.

Scarborough, R.B., 1975, Chemistry and age of late Cenozoic air-fall ashes in southeastern Arizona: Tucson, University of Arizona, M.S. Thesis, 107 p.

Shearer, J.E., 1988, Gypsum deposits of the San Pedro Valley, Arizona, with emphasis on the Thunderbird Gypsum property: SME Annual Meeting, Phoenix, Arizona, January 25-28, 1988, Society of Mining Engineers, AIME preprint 88-58, 3 p.

Shenk, J.D., 1988, The geology and development of the White Cliffs diatomite deposit: SME Annual Meeting, Phoenix, Arizona, January 25-28, 1988, Society of Mining Engineers, AIME preprint 88-129, 4 p.

______, 1990, Economic geology of the White Cliffs diatomite deposit, Mammoth, Arizona: University of Arizona, M.S. thesis, 157 p., 7 plates, scale 1:12,000.

______, 1991, Descriptive model of lacustrine diatomite, in Orris, G.J., and Bliss, J.D., 1991, Some industrial mineral deposit models: descriptive deposit models: U.S. Geological Survey, Open-file report 91-11A, p. 23-25.

Utley, K.W., 1980, Stratigraphy of the Pliocene Quiburis Formation, near Mammoth, Arizona: Tempe, Arizona State University, M.S. thesis, 178 p., 2 plates, scale 1:24,000.