Arizona Bureau of Geology and Mineral Technology

FIELDNOTES

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ARIZONA'S BACKBONE: THE TRANSITION ZONE

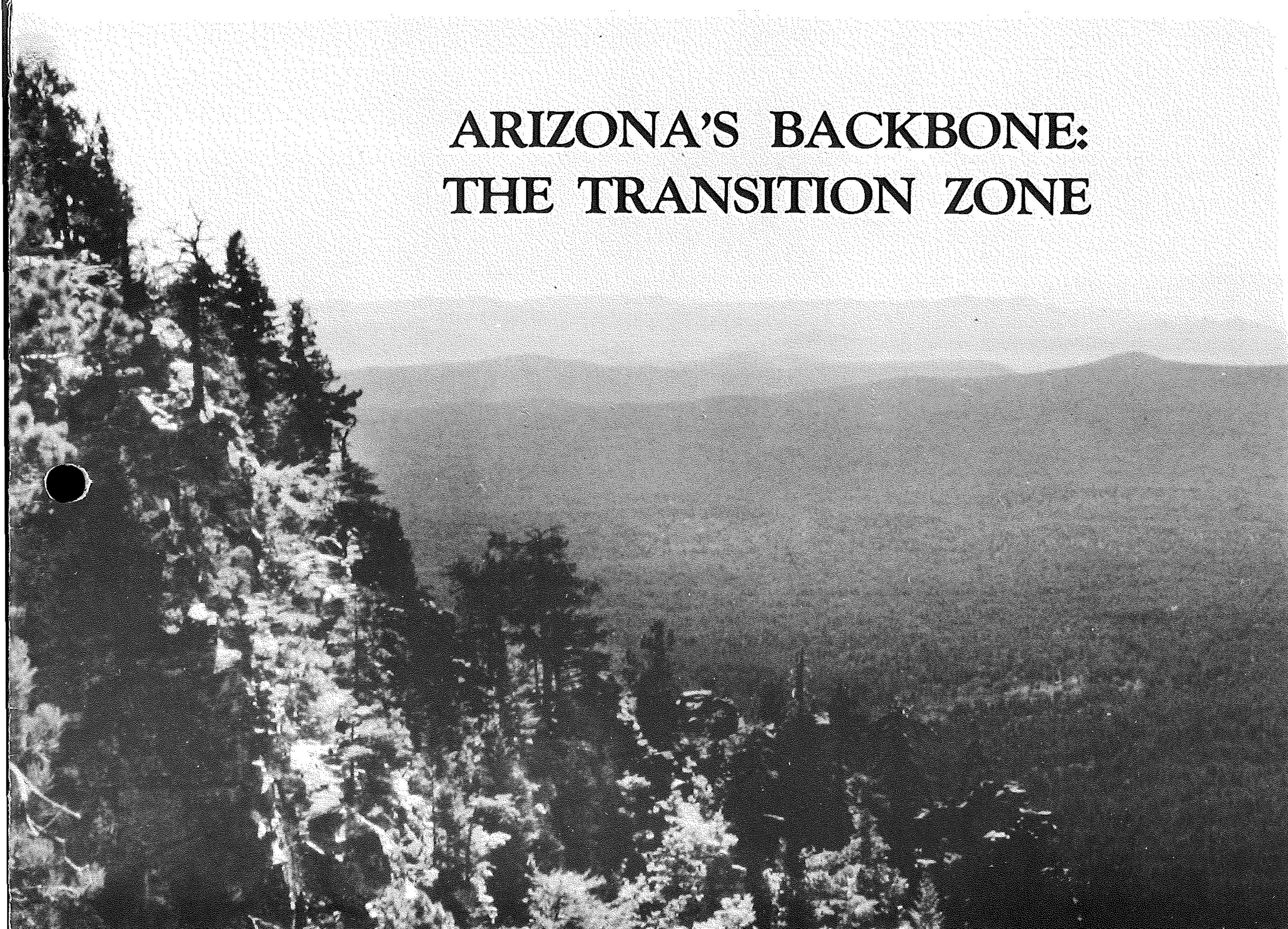

Figure 1. A southerly view into the mountainous terrain of the Transition Zone from the edge of the Colorado Plateau province (Mogollon Rim).

by H. Wesley Peirce

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Because Arizona is a land of geologic diversity, it is blessed with a kaleidoscope of fascinating landscapes. The resulting variety of ecologic habitats is reflected in the State's unusual array of flora, fauna, and land uses.

Physiography, or lay of the land, because of its wide impact, is a fundamental aspect of the earth and its political subdivisions. For more than 80 years, geologists and geographers have been defining and redefining Arizona's basic physiographic attributes. Peirce (1984) reviewed these schemes and, based upon an updated geologic understanding, suggested further modifications. Whereas all schemes recognize that Arizona contains two of the major physiographic provinces of the western United States, they differ on how to define a boundary between them. One of these large provinces, the Colorado Plateau (CP), occupies parts of four states, including the northeastern half of Arizona. The other, the Basin and Range (BR) province, involves eight states and occupies much of the southwestern part of Arizona. Most geologists have not continued to support this simple bipartite subdivision in central Arizona because they do not believe that it conveys the true nature of the central part of the State. The answer seems to be the recognition of a transition.

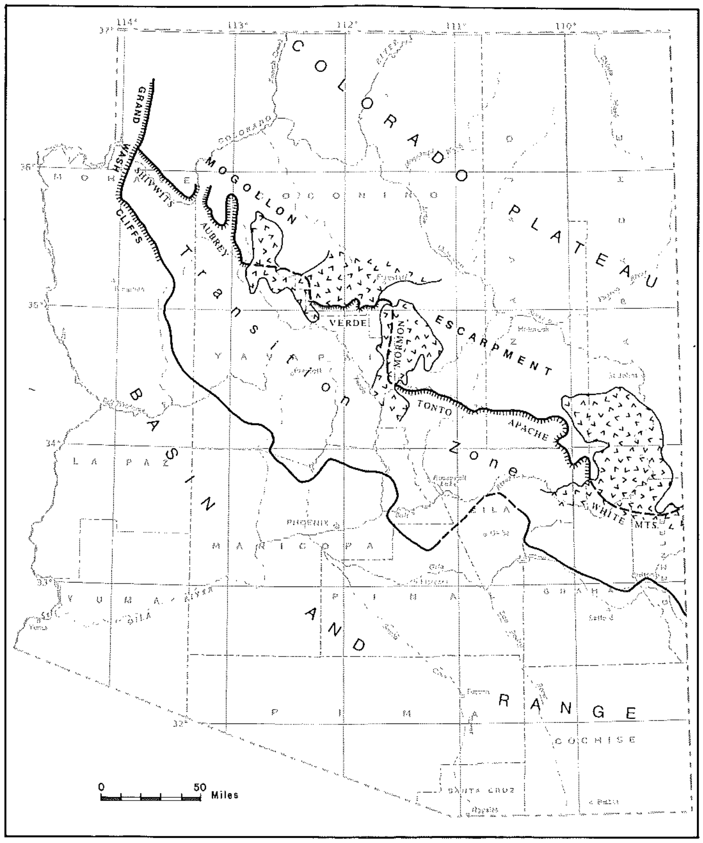

Figure 2 (above). *Boundaries of physiographic provinces in Arizona, as suggested by Peirce, 1984.*

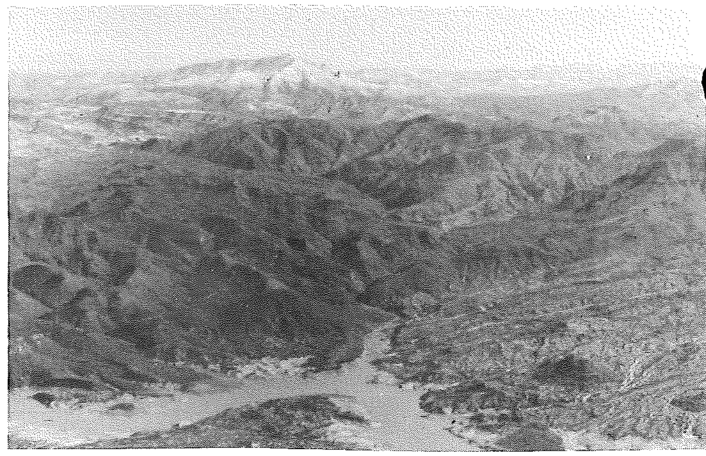

Figure 3 (top right). *Looking northeast across Bartlett Reservoir on the Verde River toward Mazatzal Peak, the highest point in the Transition Zone at 7,888 feet. The Sierra Ancha, on the skyline at right, is within the Transition Zone.*

Figure 4 (bottom right). *A northerly view into the Transition Zone showing Saguaro Lake on the Salt River, the Superstition volcanic field in right center, and Four Peaks (elevation: 7,657 feet) in the snow-capped Mazatzal Mountains. The rocks of the Mazatzal Mountains are among the oldest known in Arizona.*

Peirce (1984) suggested that an expanded, formally defined Transition Zone (TZ) be considered in subdividing Arizona physiographically (Figures 1 and 2). This article assesses the importance of the TZ and suggests that it be recognized as one of the State's three basic physiographic subdivisions.

Definition and General Characteristics

Any definition of the TZ must consider the two major provinces that flank it. The classic CP and BR provinces differ markedly in their geologic and topographic attributes. Simply put, the BR region has been severely broken by geologic processes, whereas the CP region has not. This contrast can be easily observed on any State map that depicts geology or topography.

The TZ trends northwest and its northern boundary with the CP is the Mogollon Escarpment, commonly known as "the Rim." Its southern boundary with the BR country is marked by the interface of extensive bedrock exposures with extensive, low-elevation, alluvial desert basins or valleys. The TZ embraces an estimated 18,000 square miles, or about 16 percent of Arizona. It is 350 miles in length and averages 50 miles in width. It extends from the Grand Wash Cliffs near Lake Mead to the New Mexico border and incorporates portions of Mohave, Yavapai, Gila, Maricopa, Navajo, Graham, and Greenlee Counties. It includes what has been informally called the central mountain region. Its highest point is Mazatzal Peak at 7,888 feet above sea level (Figure 3) and its lowest is about 1,500 feet near the confluence of the Verde and Salt Rivers.

Although much of the TZ is more than a mile high, its average elevation is intermediate between the higher plateau rim and the lower southern desert basins. The topography is magnificently diverse and features deep canyons (Salt River), high peaks (Four Peaks; Figure 4), and a myriad of interspersed mesas, valleys, and small mountains. Because it contains topographic aspects of *both* the CP and BR provinces, the TZ actually bears little resemblance to either.

The TZ is the surface-water province of Arizona (Figures 3 and 4). The Mogollon Rim is a drainage divide and topographic impediment that, together with the TZ, stimulates precipitation by forcing the prevailing northerly flows of warm, moist air to higher, cooler elevations. Much of the precipitation (rain and snow) from storms falls within the TZ drainage area, where surface runoff is augmented by immediate rainfall and snowmelt or by delayed runoff (spring flow). The TZ, being largely a region of bedrock and steep stream gradients, tends to promote surface flow and inhibit wholesale infiltration into the subsurface. Consequently, rapid rises in streamflow are the dominant natural hazard. Phoenix stands in a low desert basin that is bisected by the Salt River, the major drainage in the adjacent TZ. Plans are being made to create additional flood-control reservoir capacity upstream in the TZ on both the Verde and Salt Rivers. These surface waters also provide recreational outlets. Thousands of boaters, swimmers, and fishermen take advantage of TZ waters every year. The zone contains six large reservoirs, including Roosevelt Lake, Arizona's largest self-contained water body.

The contrast of the TZ with flanking regions is also expressed in the vegetation (University of Arizona, 1963). Chaparral and juniper-pinyon-oak woodland, typical of intermediate elevations, are dominant. Ponderosa pines occupy islands of higher elevation and desert scrub occurs in small areas of low elevation. Because of limited soil distribution and water availability patterns, agriculture is negligible in the TZ. Cattle ranching, however, is significant.

Wildlife populations, taking advantage of TZ life-supporting attributes, also tend to be distinctive. Some of the best bear habitat in the western United States is found in the TZ, and Arizona's largest antelope herds thrive in its northwestern section. Most of the bald-eagle nesting pairs in the State take advantage of riparian strips along its perennial waterways. An otter reintroduction program by the Arizona Game and Fish Department is underway in the lower Verde River section of the zone.

Rock and mineral attributes of the TZ are unique in several respects. The TZ, as will be explained later, has the most extensive display of Arizona's oldest rocks, rocks that give the region much of its bold character. In Arizona a type of ore deposit known as a "massive-sulfide deposit" is associated only with these oldest Precambrian rocks, which are about 1.8 billion years (b.y.) in age. Unlike the more famous porphyry coppers, which are disseminated, low-grade deposits, massive-sulfide deposits, such as those found near Jerome, are compact and high grade. The Verde mineral district, which includes Jerome, yielded ores (largely copper, zinc, and silver) valued at $3.5 billion at today's metal prices. Typical porphyry copper deposits occur at Bagdad and near Prescott, and gold placers in the Prescott region attracted early interest. Ninety-five percent of the mercury produced in Arizona came from a cluster of mines in the Mazatzal Mountains district. Numerous small uranium deposits, some of which were exploited, are known in the Sierra Ancha and adjacent regions. The expanse of Precambrian rocks in the TZ, their relationship to early growth of the continent, and their mineralization make them a target for ongoing research and exploration.

Significant deposits of nonmetallic materials have also been found in the TZ. A narrow, northwest-trending belt of good-grade, lower Paleozoic (which overlies the Precambrian) limestone crops out in the northwest part. Limestone from this belt supports a large lime plant just east of Peach Springs, as well as a cement plant in the Verde Valley that today supplies much of Phoenix's cement, but was first built to supply cement for Glen Canyon Dam. A salt deposit in the Verde Valley was mined by Indians. Some of the highest quality chrysotile asbestos in North America was mined from the Sierra Ancha-Salt River region. Schist used as decorative facing stone is quarried near Mayer.

Fourteen of the State's 49 wilderness areas are within the TZ. In other words, the TZ, which contains 16 percent of Arizona's total acreage, contains nearly 30 percent of its wilderness areas, a proportion that clearly indicates this area's relative remoteness and unusual qualities.

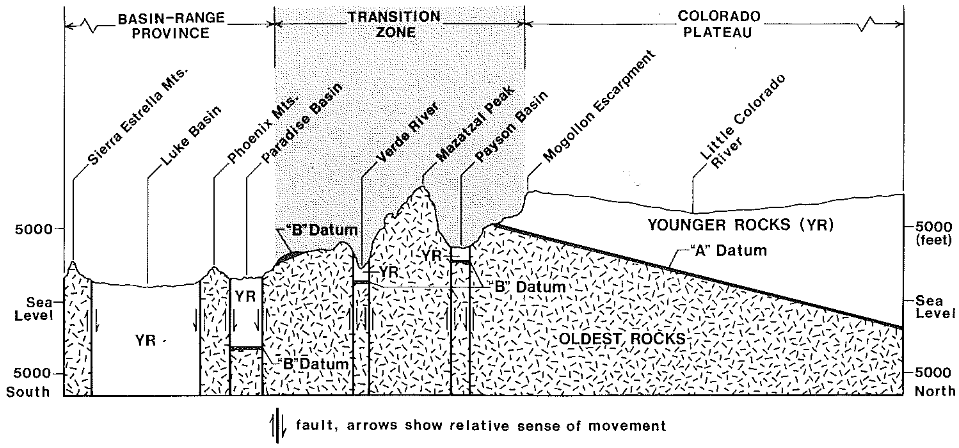

Figure 5. *Schematic diagram showing present structural highness of Precambrian rocks in the Transition Zone (TZ) with respect to the adjacent Basin and Range (BR) and Colorado Plateau (CP) physiographic provinces. The "A" Datum is the contact between Precambrian (oldest) and Paleozoic (younger) rocks in the CP province; the "B" Datum is the contact between Precambrian and Tertiary (younger) rocks in the BR province.*

Structural Processes

Terrain differences are direct indicators of geologic differences. The State's three physiographic regions reflect three contrasting sets of geologic conditions. The most fundamental physical parameter that controls these differences is "structure."

"Structure" is a term that describes the regional arrangement and geometric shapes (architecture) of rock masses. Rock masses can be unaffected, pulled, pushed, bent, broken, tilted, raised, and lowered to varying degrees and on different scales. The older the rock mass, the more likely it is to have undergone one or more episodes of structural disruption. An area's structural history can be determined by making systematic observations and interpretations of rock positions. Many geologists have contributed to unraveling Arizona's geologic history, and much contemporary geologic research is devoted to a better comprehension of its structural character.

The earth's surface features are the result of interaction between internal and external forces. These forces operate unequally, creating irregularities on the earth's surface. Structural disruption causes surface highs and lows. Once differential elevations exist, other physical and chemical processes (e.g., weathering, transport, and deposition) begin to attack the highs and fill the lows in an effort to regain a planar surface of equilibrium. Structural highness (uplift) brings older rocks closer to the surface. This is why Arizona's oldest rocks are so well exposed in the TZ.

Relative structural highness can be easily identified by noting the elevations of traceable reference surfaces. One such surface in the CP province is the contact between the Precambrian and Paleozoic rocks near the bottom of the Grand Canyon. This contact or interface ("A" Datum; Figure 5) has been penetrated in deep drill holes elsewhere beneath the plateau surface and resurfaces near the TZ-CP boundary (Mogollon Escarpment). Elevations of this reference contact are 1,600 feet *below* sea level beneath Black Mesa in northeastern Arizona; 3,000 feet above sea level at the Grand Canyon; 5,000 feet above sea level at the TZ-CP boundary; and some unknown amount above 7,900 feet at Mazatzal Peak in the TZ. The elevation of the reference surface at Mazatzal Peak is unknown because erosion has removed the overlying Paleozoic rocks and an unknown thickness of Precambrian rocks. The elevational extremes (-1,600 and +7,900) differ by almost 10,000 feet. Unlike the Grand Canyon, where the datum is beneath 4,000 feet of nearly flat-lying sedimentary rock, the datum on Mazatzal Peak is above the surface and is at least 5,000 feet structurally higher than at the Grand Canyon. This reference surface is also 2,000 feet higher at the plateau margin than at the Grand Canyon, and at least 3,000 feet higher at Mazatzal Peak than at the plateau margin. All data lead to the conclusion that presently there is a southerly rise in regional structure that culminates within the TZ. This rise exists because certain rock strata in the CP are warped and gently tilted downward toward the northeast (Figure 5). Geologic evidence indicates that some of this tilt was imposed prior to 90 million years (m.y.) ago when these CP rocks were much lower in elevation than they are now.

Mazatzal Peak represents the maximum elevation of Precambrian rocks in the TZ. Even the *lower* surfaces on these old rocks, for the most part, are at higher elevations than the same rocks beneath the CP. Overall, this elevational difference renders the Precambrian rocks of the TZ structurally higher than those in the CP and helps to explain why these oldest rocks appear at the surface in the TZ. It also explains why the classic Grand Canyon sedimentary rock sequence of Paleozoic age is absent in the Phoenix region: it has been eroded from areas that remain, or once were, structurally higher than the CP now is or once was. This condition applies to much of central Arizona; structural highness,

Figure 6. *Looking north into the Transition Zone. Flat-topped, eroded mesas are capped by the lava (volcanic rocks) of "B" Datum (see Figure 5). Although locally the lavas overlie slightly older sedimentary materials (white foreground), they generally overlie Arizona's oldest rocks. The sediments and volcanics, which are about 15 to 17 m.y. old, are believed to have accumulated in a previously existent erosional valley. They are now being destroyed by a continuing episode of erosion. Drainage is to the south into the topographically lower country of the Basin and Range province.*

past and present, promotes erosion.

A reference surface is also needed for structural comparison of the TZ with the BR province to the southwest. The sedimentary rocks used as a reference surface in the CP province have been eroded away in the BR province. Although Precambrian rocks are present in the BR region, they tend to be covered by much younger rocks than in the CP region to the north. The contact between the Precambrian rocks and these younger rocks serves only as a reference surface for interpretation of events that have happened since the development of these younger rocks ("B" Datum, Figures 5 and 6).

One of the characteristics of the BR province is the expanse of low-elevation desert valleys or basins. Drill samples and other information indicate that deep structural basins commonly underlie the low desert surfaces. Relative to the TZ, these basins are downdropped along faults. Available data indicate that downdrops of 6,000 to 8,000 feet are not unusual; displacement may be as much as 10,000 feet in some areas. Paradise Valley north of Phoenix, for example, represents a BR basin adjacent to the TZ. A drill hole at the north end of the basin was stopped above the younger reference datum at an elevation of 3,676 feet *below* sea level. To the north near Carefree, the outcropping datum at the edge of the TZ is at an elevation of 2,500 feet *above* sea level (Figure 6). The minimum structural differential of these two points, therefore, is about 6,000 feet, with the basin floor as the low point and the TZ outcrop as the high point. The causal mechanism for this structural disruption is faulting. A minimum differential of more than 11,000 feet, however, exists between Precambrian rock in the Paradise Valley basin of the BR province (-3,676 feet) and Precambrian rock at Mazatzal Peak in the TZ (+7,900 feet). Faulting accounts for 6,000 feet; the remaining 5,000 feet that is confined to the TZ itself was inherited *prior* to the BR faulting event and is subject to investigation of the actual cause(s) of this internal differential.

The time span between "A" Datum and "B" Datum represents a missing record of about 500 m.y. in the Phoenix and TZ regions where all Paleozoic and Mesozoic strata are absent. Where this missing record prevails, there is no simple way of reconstructing all of the structural movements that have affected the very old crystalline rocks. The only conclusions to be drawn here might be these: (1) in the CP, the older "A" Datum was tilted so that structural highness prevailed to the south; and (2) "B" Datum shows that there is considerable differential elevation, much of which is caused by faulting that leaves the TZ structurally high relative to the flanking basins in the BR province. The net result of geologic history has been the creation of a TZ, which, because of its structural highness relative to the CP and BR province basins, features extensive exposures of Arizona's oldest rocks (Figure 5).

Erosional Events

Two basic processes create differences in land elevation: (1) structural processes, or the differential movement of rock masses, as discussed earlier; and (2) erosion, which causes local land-surface differentials. The local relief caused by erosion in the Grand Canyon exceeds 4,000 feet. This local relief, however, could not exist if there were no *regional* structural differential to induce erosion (i.e., if there were no regional relief to cause the river to downcut). Where surface relief is involved, therefore, caution is needed in assigning immediate causal factors. This is especially true of the TZ, where spectacular surface irregularity is characteristic. The complex, rugged terrain results from an incompletely understood history that includes multiple structural and erosional events. Whatever the details, the TZ is now, from a structural point of view, the backbone of Arizona (Figure 5).

The TZ is geologically unique because it preserves a geologic record that has not been found in the larger provinces that bound it. An important aspect of this record is the preservation of evidences of ancient erosion that indicate a complex history of terrain development. Because structural and erosional events are closely related, erosional events can be a key to recognition of causal structural events. Another clue to a structural happening, as already mentioned, is an out-of-place datum. A good example is the occurrence of fossil marine oysters and clams at 7,000 feet above sea level along the edge of the CP near Show Low. The enclosing sandstones, believed to be about 95 m.y. old, were deposited in a shallow sea that covered much of northern Arizona and adjacent states. Based on the belief that sea level at that time was not greatly different than at present, most geologists would say that the fossils have been uplifted and the CP province structurally raised several thousands of feet sometime during the last 95 m.y. A question remains, however: what was uplifted when? This is really two questions and neither lends itself to easy answers. In Arizona, such answers cannot be found in the CP province; rather, they must be sought in adjacent regions, especially the TZ. The TZ, as discussed earlier, was uplifted more than the CP; the "what" question must therefore include the TZ as well.

The TZ, as already stated, contains a complex and fascinating erosional history that necessarily reflects a complex history of structural movement. An erosional history, such as one that is reflected in the Salt River drainage system, might be related to the major regional uplift that drove the seas from Arizona and left the oysters high and dry.

Much of the Salt River flows within the TZ. This drainage system can be divided into segments that differ markedly in terrain characteristics. The 18-mile-long segment between Canyon Creek to the northeast and Lake Roosevelt to the southwest, in which the river flows southwest, is especially intriguing. Relief between the river and the regional high point in the adjacent Sierra Ancha (Aztec Peak - 7,694 feet) is about 4,700 feet. This is more than the relief in the Grand Canyon at El Tovar on the south rim.

Upstream from Canyon Creek is the more familiar Salt River Canyon segment that is crossed by State Highway 77 between Globe and Show Low. Because of the low width-to-depth ratio, this portion is impressive compared to the Sierra Ancha segment, which has twice the relief, but is also much broader (Figure 7). Why are there such form differences in adjacent segments of the same river?: they have contrasting pre-Salt River geologic histories. Evidence now indicates that the shallower and narrower west-trending Salt River Canyon segment was carved by the Salt River since 12 m.y. ago. In contrast, the deeper and broader southwest-trending Sierra Ancha segment has a notably earlier history of canyon-cutting (prior to 30 m.y. ago) by a river that drained towards the northeast — 180° opposite to the present flow direction (a view first expressed by Peirce, 1982).

The ground work for establishing this idea of paleotopography in the Sierra Ancha segment was actually laid by N. H. Darton (1925, p. 229, 230), a most perceptive field geologist. Although he clearly diagrammed the critical factors, he did not discuss or otherwise acknowledge their implications. Likewise, although Wilson and others (1959) clearly mapped paleocanyon relationships, they never acknowledged or discussed them. The only explanation for these uninterpreted observations seems to be that they were subordinate considerations at the time. Had these geologists had the benefit of present-day age-dating techniques, they would probably have grasped the antiquity behind these relationships and thus been more impressed with their own findings. The important structural implications behind these and subsequent observations are reviewed below.

The contrast between the Sierra Ancha and Salt River Canyon segments is sharply defined by the slightly west-of-north-trending Canyon Creek Fault (Figure 7). Finnell (1962) has shown that there were at least two episodes of movement along the Canyon Creek Fault, each with an opposite sense of movement relative to the other. The early movement, before 30 m.y. ago, *raised* the west side (relative to the east) several thousands of feet. This early movement promoted about 4,000 feet of canyon-cutting erosion on the high western block and defined the ancestral southeastern edge of the Sierra Ancha segment (Figure 8A). This drainage flowed northeastward from the high block towards the CP province. Whether or not it drained onto the CP remains an elusive point of research. After the canyon was incised, later movement *dropped* the western block (relative to the east) several thousand feet to its present position, where vestiges of the early canyon could be preserved and the new southwesterly flowing Salt River could establish itself. This later dropping of the west side left the east side high and thus promoted the younger cycle of canyon cutting that characterizes the modern Salt River Canyon segment (Figure 8B).

Such ups and downs of the land surface, though sometimes difficult to document, are

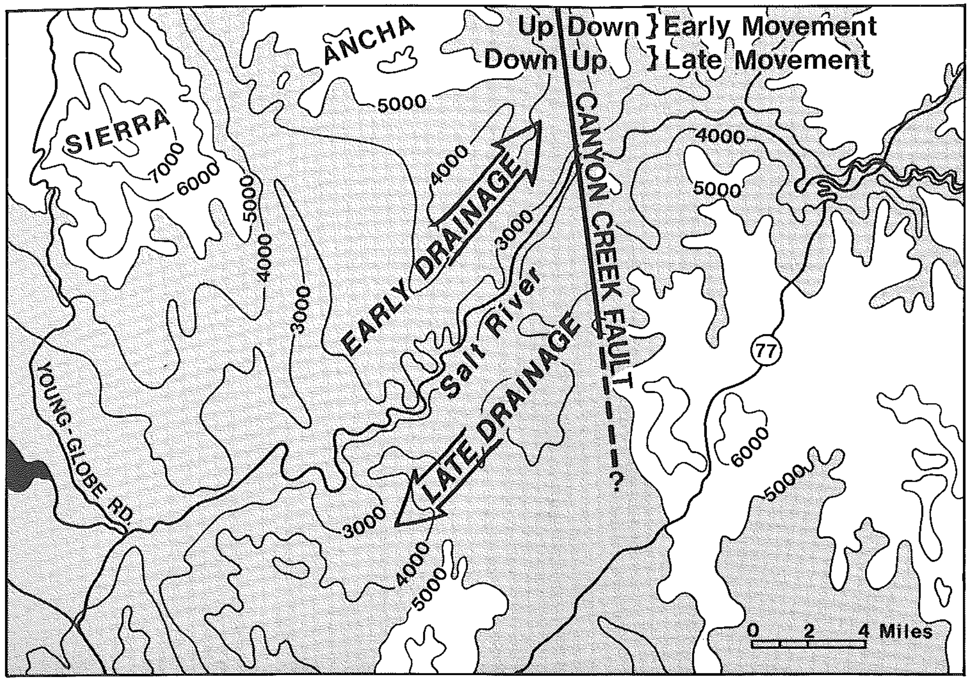

Figure 7. *Map depicting contrasting forms of two canyon segments occupied by the Salt River in the Transition Zone; the Canyon Creek fault is the boundary between the two segments. Shading of elevations below 5,000 feet illustrates the comparative widths and contours the overall relief. See Figure 8 for faulting history.*

not unusual. In any given locality, earth stresses and their manifestations vary through time. The early indication of pre-30-m.y. uplift cited here is based upon local evidence. Although a much larger region undoubtedly underwent structural adjustment, it is not yet possible to delimit with certainty the larger zone that was affected. The rock units that accumulated in the bottom of the paleocanyon are the same as those that overlie the large copper deposits in the Miami, Globe, and Ray areas. It seems likely, therefore, that the uplift-erosion episode that produced the paleocanyon may have also caused the unroofing of these ore deposits. Young (1982) postulates that 180 miles to the northwest other TZ paleocanyons, also with 4,000 feet of relief, were eroded by north-flowing drainage. Dating methods indicate that these paleocanyons and the Sierra Ancha segment are similar in age. Such evidence suggests that the TZ was once even structurally higher than it is today and that it has foundered since its heyday.

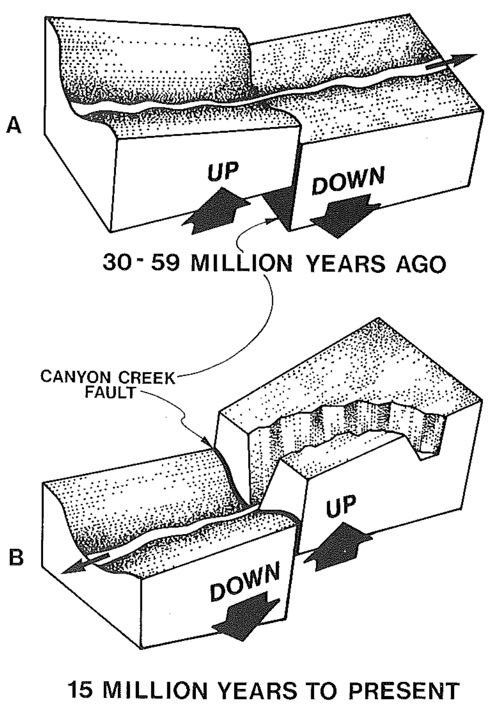

Figure 8. *Block diagrams illustrating how two episodes of movement on the Canyon Creek fault influenced drainage development and canyon styles along the course of the Salt River. (See also Figure 7.)*

This structural information from the TZ enables further interpretation of the oyster fossils at 7,000 feet along the southern edge of the adjacent CP province. It seems probable that their structural position was influenced by an uplifting event that induced canyon-cutting in the TZ during and after formation of the youngest of the nearby copper deposits (59 m.y. ago) and before rock units began to accumulate on the irregular erosional surface 30 m.y. ago.

Conclusion

A Transition Zone, in one form or another, deserves to be recognized as one of Arizona's three basic physiographic subdivisions. Proportionally, its contributions to the State (water, wildlife, scenery, wilderness, recreation, minerals, etc.) far exceed its size. Its magnificent ruggedness and related inaccessibility stem largely from a complex and poorly understood structural and erosional history. Because of its central position and because, in a structural sense, the Colorado Plateau and Basin and Range provinces now tend to fall away from it, the Transition Zone qualifies as Arizona's "backbone." Further research in the Transition Zone could significantly aid understanding of the geologic history of the Southwest in general and Arizona in particular.

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LANDSCAPES OF ARIZONA

"The 295,146 square kilometer surface of Arizona contains some of the most striking, varied, and beautiful landscapes that can be formed by geologic and climatic processes. Although the surface of the state has been quiescent at times, more often it has undergone compression, stretching, uplift, and sinking. These processes have created towering mountains, sheer massive scarps, and deep basins and canyons. Violent eruptions of lava or rock fragments or smoothly flowing lavas from volcanos have added to landscape formation. At different locations within the state, one can see exposures of every type of rock from the finest and softest silts and clays to the hardest crystallines. Minerals in certain exposed rocks present drab colors in some areas or a vivid kaleidoscope of colors in others.

"Climates over the state that helped mold the landscape have been and still are as varied as the landscapes themselves. In the past, as today, parts of the state have had long, monotonous, hot, dry summers. At the higher elevations, however, the winters were cold and bitter; the cold at times was sufficient to form mountain glaciers which slowly ground their way down valleys. Not always were the skies clear. During many of the violent volcanic eruptions, huge quantities of dust and ash clouded the air many kilometers away from the craters, and associated obnoxious to lethal gases drifted with the winds. At times the skies were filled with dust and sand as strong winds carried these materials to every part of the state.

"What we see today is the end result of millions of years of nature's activity. The dry climate of Arizona has helped keep these sharp, vivid landscapes exposed by not weathering the rock to where it could form a deep, protective cover of soil and other depositional materials.... The beauty of the landscape needs no qualification and can be appreciated with no further geological investigation. However, people are inquisitive creatures and often wonder-Why is that mountain or canyon there? Why are these rocks so red and those rocks so black? Why are some rocks evenly stratified and some very massive and crystalline? Many other such questions occur to the observer of the landscape; undoubtedly the answers to such questions will enable the observer to experience a greater satisfaction than that of simple aesthetic appreciation."

The preceding text is excerpted from the preface of *Landscapes of Arizona—the Geological Story*, a recent book published by the University Press of America and edited by T. L. Smiley, J. D. Nations, T. L. Pewe, and J. P. Schafer. This 505-page volume summarizes geologic work that pertains to interpretation of landscape development in Arizona. In preparation for 10 years, the book comprises 17 chapters, each written by one or more geologists experienced in working on Arizona geology. The semitechnical material is accompanied by a glossary, which explains terms that may be unfamiliar to the layperson. Basic principles and concepts of landscape formation are discussed in the text, as well as specific types of landforms in certain areas of the State. Topics include Cenozoic plant and animal fossils, climatic changes during landform development, volcanic landforms, glaciation, eolian (wind-formed) landforms, plateaus, canyons, alluvial fans and pediments, desert basins, etc. Numerous photographs and several maps are included to illustrate and locate various geologic features in Arizona.

Landscapes of Arizona—the Geological Story may be purchased from University Press of America, Inc., 4720 Boston Way, Lanham, MD 20706. Single copies cost $36.50 each, plus $1.25 for shipping and handling.

Geological Survey Branch Hosts 21st Forum on the Geology of Industrial Minerals

by H. Wesley Peirce

The 21st Forum on the Geology of Industrial Minerals, held in Tucson April 9-12, 1985, was hosted by the Arizona Geological Survey (AGS), the Geological Survey Branch of the Arizona Bureau of Geology and Mineral Technology. The 21st forum boasted a record attendance: 154 participants (not including 28 spouses) represented 28 states, Canada, and Mexico. Non-Arizonans composed 75 percent of the total number of registrants, a percentage that clearly demonstrates the national and international character of the forum.

The term "industrial minerals" is synonymous with "nonmetallic minerals and rocks." In most states it is the industrial minerals, or nonmetallics, that dominate the mining industry. In a few western states such as Arizona, the nonmetallics, though vitally important, play second fiddle to the metals.

The earth is a storehouse of common, relatively cheap materials suitable for construction and other uses. The bulk of the Nation's cities, homes, and streets is constructed from mined and processed nonmetallic materials. In the East and Midwest, many geologists are employed by industrial-mineral firms. Because of the basic importance of nonmetallic materials, Bob ("The Geologic Column") Bates, while a professor at Ohio State University, organized the first annual forum as a place where industrial-mineral geologists and engineers could meet to share observations, problems, and insights in an atmosphere of friendly informality (Figure 1).

The program in Tucson featured five field trips for registrants and spouses, 23 technical papers, and a banquet with after-dinner program. An independently arranged, postmeeting float trip on the Colorado River was offered to registrants and their spouses. Thirty-seven persons took advantage of this rare opportunity.

PREMEETING TRIPS

Two premeeting trips were offered to registrants and their spouses. The main trip was a visit to zeolite deposits; the second trip provided an opportunity to view an open-pit copper-molybdenum mine.

Under the leadership of Ted and Dan Eyde (Tucson industrial-mineral consultants), 70 persons piled into vans for a trip to Bowie to view the largest chabazite (a zeolite mineral) deposit in the United States. Highlights of this

Figure 1 (right). Larry Fellows (left), State Geologist and Assistant Director of the Arizona Bureau of Geology and Mineral Technology, and Wes Peirce (center), Principal Geologist at the Bureau and General Chairman of the 21st Forum, converse with Bob Bates (right), Professor Emeritus at Ohio State University and founder of the Forum on the Geology of Industrial Minerals.

Figure 2 (bottom left). Zeolite (chabazite) pit near Bowie, Arizona. Overburden is removed to expose 6-inch-thick "ore" horizon (see Figure 3). Chabazite is stockpiled and trucked to the railroad as needed.

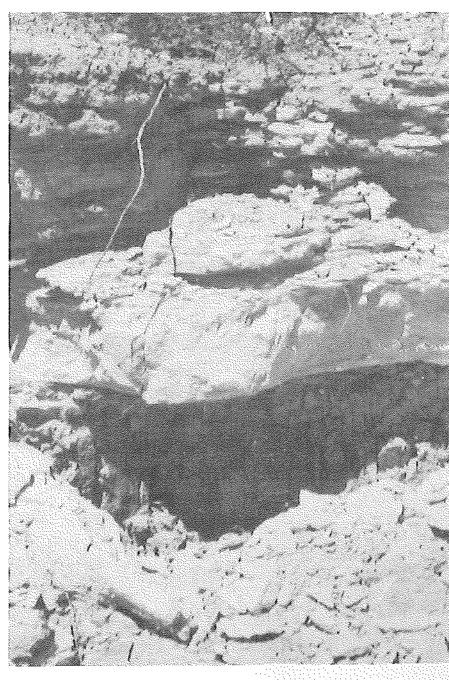


Figure 3 (bottom right). Six-inch-thick, high-grade chabazite deposit is overlain by impure beds.

excursion are shown in Figures 2 and 3.

Another van load left for the Duval Sierrita copper mine, where Dan Aiken, chief mining geologist, took visitors into the pit for a close look at ore. They later drove through the mill complex and viewed the mineral-concentration process. The timing of this visit was opportune because mine production had just reached an all-time high. Duval Corporation's Dean Lynch and Dan Aiken were responsible for making this experience possible.

TECHNICAL SESSIONS—APRIL 10

Morning

After brief opening remarks by the general chairman (Wes Peirce), the group was officially welcomed to Arizona by Dr. Richard A. Swalin, Dean of the University of Arizona College of Engineering and Mines and Director of the Arizona Bureau of Geology and Mineral Technology. Dr. Larry Rooney, U.S. Geological Survey, chaired the morning session, which included one overview and seven regional papers.

Jim Dunn (Dunn Geoscience Corporation) presented the first paper, "Mining and the Environment—Finding Common Ground." Jim perceives that there is a "war" going on in the technologic, philosophic, and political trenches between mineral-industry and environmental leaders, a war to which much of the public is oblivious. Despite this battle, he believes that there are goals common to both factions, goals that all reasonable and caring individuals can seek and attain. Jim suggests that the environmental fervor expressed by well-intentioned idealists has been promoted and perpetuated in this country by media hype. He also thinks that, in response to the demands of reasonable persons, a wave of credibility is developing that will replace environmental extremism with basic, well-balanced information. Those associated with the mineral industry, Jim suggests, can help further this dialogue and sharing of scientific data by encouraging the promoters of good sense as they handle issues rendered controversial by the media.

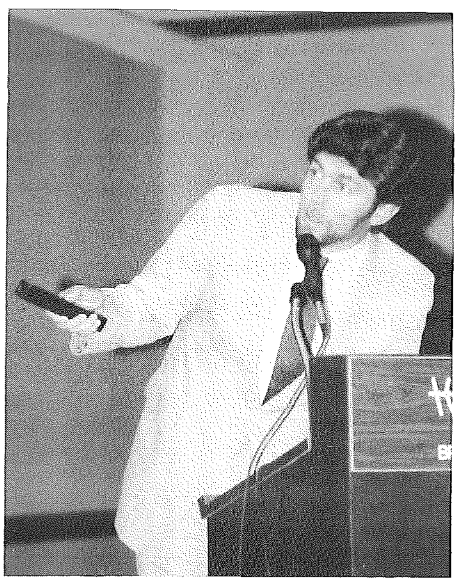


Figure 4. Ken Santini, Anaconda Minerals Company, talks about evaporite deposits in California.

Steve Reynolds (AGS geologist) emphasized that geologic framework controls the existence and distribution of all mineral and rock deposits. He discussed highlights of Arizona's geologic history of 1.8 billion years and explained how useful earth materials associate with geologic events that occurred during that time. He pointed out that much of Arizona, geologically speaking, remains a frontier that has significant potential for the occurrence of unrecognized earth materials useful to mankind.

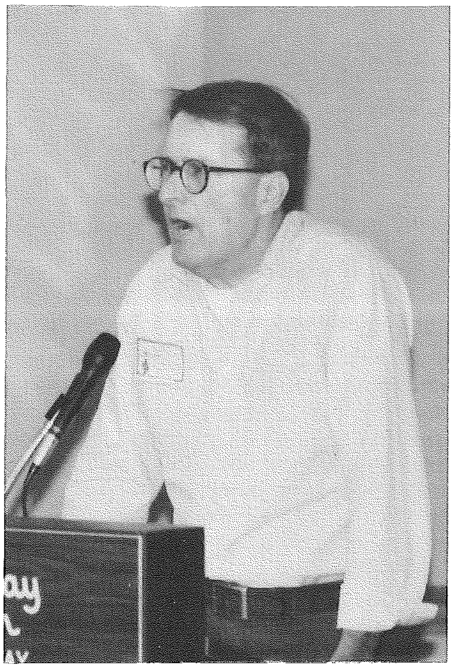


Figure 5. Malcolm Ross, U.S. Geological Survey, discusses "asbestos" and the public health issue.

Wes Peirce (AGS geologist) talked about Arizona's industrial (nonmetallic) minerals and rocks. He reminded the participants that in 1981, Arizona was ranked number one in the Nation with respect to the value of nonfuel-mineral production ($2.56 billion). About 7.5 percent of this value, or $192.5 million, can be attributed to nonmetallic products. In this same year, at least 225 industrial mineral and rock deposits were being worked to produce about 10 tons of material per Arizona resident. Many of these "bread-and-butter" materials (cement, lime, sand, gravel, stone, salt, clays, etc.) are fundamental to the construction industry. Consequently, product demand is directly related to population growth and economic strength. Growth in the Arizona sun-belt dictates concomitant growth in the production of fundamental industrial-mineral commodities.

Keith Papke, Nevada Bureau of Mines and Geology, summarized industrial-mineral production in Nevada and Bryce Tripp, Utah Geological and Mineral Survey, gave a similar orientation for Utah. Joaquin Ruiz, Department of Geosciences, University of Arizona, summarized Mexico's industrial-mineral production. Rounding out the regional story, Steve Kupferman, Kaiser Cement Corporation, discussed the geology of cement raw materials in Arizona and southern California. Howard Brown, Pluess-Staufer (California) Inc., talked about the stratigraphy, tectonic setting, and industrial minerals of Paleozoic rocks in the Mojave Desert of California.

Afternoon

The second technical session, chaired by Michael N. Greeley, Arizona Department of Mines and Mineral Resources, featured nine papers. Dennis Bryan, Engineering Testing Associates, discussed natural lightweight aggregates of the Southwest. Gerald Allen, The Earth Technology Corporation, outlined an approach to locating high-quality aggregates in the Basin and Range province. Ken Santini, Anaconda Minerals Company, provided a geologic evaluation of a brine-saturated evaporite deposit in the southern portion of Searles Lake, California (Figure 4).

Rules and regulations governing mineral development are fundamentally important, and two papers focused on this subject. Terry Maley, U.S. Bureau of Land Management, talked about acquisition of federally owned industrial minerals; and Edward Spalding, Arizona State Land Department, discussed mining industrial minerals on Arizona State Trust lands.

The media frequently place health-related matters before the public. Malcolm Ross, U.S. Geological Survey, talked about minerals and health as related to the "asbestos" problem (Figure 5). Dr. Ross, one of the "promoters of good sense" to whom Jim Dunn referred in his talk, confronts the front-page issue of "asbestos" with scientific data and analysis often neglected by media personnel.

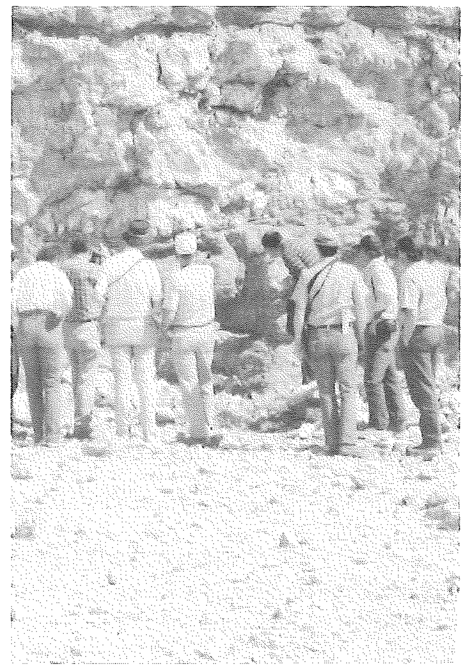
Two additional papers ended a productive afternoon session: Mark Bowie, New Mexico Bureau of Mines and Mineral Resources, compared zeolite deposits in Arizona, New Mexico, and Texas; and John Welty, University of Arizona graduate student and AGS research assistant, discussed the geology and industrial uses of Arizona's volcanic rocks. John emphasized the importance of past volcanic processes in making useful products. Furthermore, he concluded that potential is high for recognition and development of new deposits of useful volcanic materials.

Concurrent with the technical sessions, Maxine Peirce guided two van loads of spouses to the Arizona-Sonora Desert Museum and the San Xavier Mission (Figure 6).

Figure 6 (right). Spouses of forum attendees visit the Mission San Xavier del Bac near Tucson. The mission site was first established in 1700 by Fr. Eusebio Francisco Kino, the "Padre on horseback." The present church, which has often been described as the best preserved and most beautiful of all missions in the Spanish Southwest, was built between 1783 and 1797.

Figure 7 (bottom left). Abandoned gypsum quarry near Winkelman in the San Pedro Valley. Bob Scarborough, Arizona Geological Survey, discusses the geology of gypsum.

Figure 8 (bottom right). Field-trip participants consider the environment in which the gypsum accumulated.



INTERIM ALL-DAY FIELD TRIPS

More than 100 persons loaded into buses and miscellaneous vehicles for the traditional interim, all-day field trip on April 11. This trip featured geology, scenery, and metallic and nonmetallic mineral operations. The route included Oracle, Kearney, Superior, and Globe. AGS geologists Steve Reynolds and Bob Scarborough provided orientation on the buses.

The first formal stop featured the center of Arizona's gypsum industry in the San Pedro Valley just south of Winkelman. A visit was made to a recently abandoned gypsum quarry used by the Gold Bond Division of the National Gypsum Corporation to manufacture wallboard at a Phoenix plant (Figures 7 and 8). Bob Scarborough, independent geologist and part-time employee of the AGS, gave an overview that emphasized the geology of late Cenozoic basins and basin-fill sedimentary deposits in southern Arizona's Basin and Range geologic province. The San Pedro Valley gypsum deposits are examples of useful materials contained in a basin-fill sequence that accumulated about 5 million years ago when camels and other vertebrates roamed the ancestral valley.

The second stop took advantage of a convenient overlook of the Ray mine, an operating open-pit copper mine owned by the Kennecott Copper Corporation. The third stop featured the State's perlite mining center near Superior, where the host was the Sil-Flo Corporation. Ground and sized perlite is exported and "popped" (expanded) elsewhere. Some of Sil-Flo's product, for instance, is used in the filtration of beer made in Dallas, Texas. Participants were given free time to collect Apache tears, which are semiprecious, dark-colored nodules of volcanic glass. Mr. and Mrs. Louis Lucero helped to make this a pleasant and informative interlude.

The field trip continued through the Queen Creek Tunnel to a lunch stop at the Oak Flats picnic area in the Tonto National Forest. After this welcomed respite, the trip proceeded to an "asbestos" mill via the copper-mining towns of Miami and Globe. Here, forum attendees received a rare, first-hand review of the "asbestos" controversy from some of the principals involved in this ongoing saga. Mr. D. W. Jaquay and his associates led a tour through their fully licensed, inoperative "asbestos" mill and provided samples of some of the highest grade chrysotile asbestos fiber in North America (Figure 9).

Concurrent with this field trip, a smaller group of forum attendees visited Nogales, Mexico and the historic sites between this

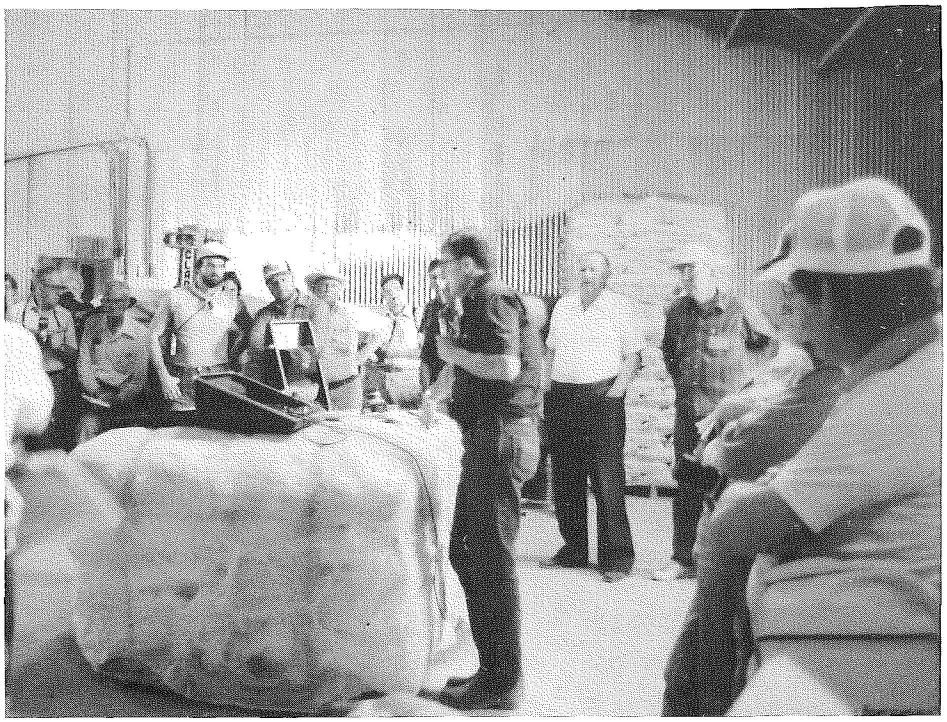


Figure 9. Field-trip participants visit the inoperative "asbestos" mill in Globe, Arizona.

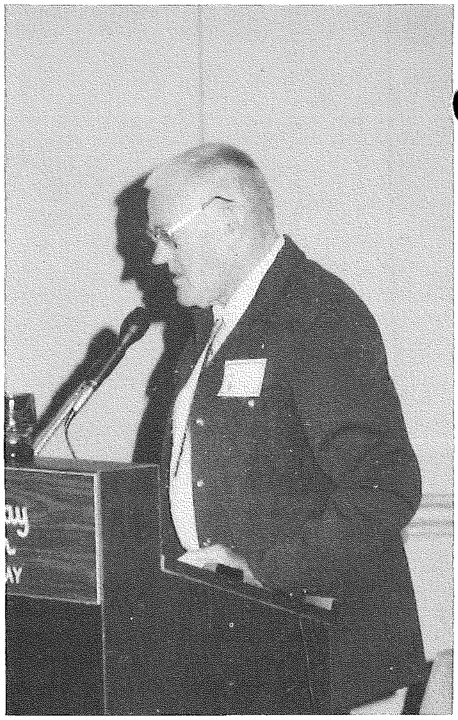


Figure 10. Don Morris, Building Products Company, discusses vitrified clay pipe.

border town and Tucson. Both trips returned to Tucson for the annual banquet. After greetings and comments from persons at the head table, Peter Kresan, geologist and noted photographer, presented an original two-screen slide program set to music, entitled "Arizona Images."

FINAL TECHNICAL SESSION

The last technical session, consisting of seven presentations, was held the morning of Friday, April 12. Dr. Larry Fellows, State Geologist and Assistant Director of the Arizona Bureau of Geology and Mineral Technology, chaired the session. With one exception, the program featured Arizona's industrial minerals: Leo Langland, Arizona Department of Transportation, talked about locating, sampling, and evaluating potential aggregate deposits; Don Morris, Building Products Company, gave an original paper on raw materials and the manufacture of vitrified clay pipe in Arizona (Figure 10); Jerry Grott, Southwest Salt Company, discussed solar salt in Arizona; Dan Eyde, GSA Resources, Inc., talked about bentonite and specialty sand deposits in the Bidahochi Formation; Ted Eyde, GSA Resources, Inc., discussed the Bowie chabazite deposit; John Rains, California Portland Cement Company, completed the program with a talk on Arizona Portland Cement Company's Rillito operation. One paper, by R. E. Miques, Bechtel Civil and Minerals, Inc., focused on aggregate for large works, using examples from outside Arizona.

CLOSING COMMENTS

Like a speeding car, the 21st Forum on the Geology of Industrial Minerals has come and gone. It is difficult to grasp and appreciate the total effort needed to conduct a successful technical meeting. Each presenter, attendee, vehicle driver, trip leader, and session chairman must contribute. The record attendance was, in large part, a tribute to the natural attractiveness of Arizona. It took, however, the contributions of many individuals, including attendees, to render this meeting a candidate for the "best-ever" forum. Maxine Peirce served as treasurer, registration chairman, arranger of spouse activities, and trip leader. Evelyn VandenDolder produced the Program With Abstracts, and Janet Christner compiled registration lists and performed other tasks. Many others aided in myriad ways. The 20 firms that generously donated to the social functions also contributed to the success of this conference.

The Bureau has extra copies of the program brochure, which contains informative abstracts of all 23 technical papers. These are available for $2.00 each. A proceedings volume will be published and available for distribution sometime in 1986.

With the 21st annual forum at a close, Arkansas awaits next year's meeting. Any State interested in hosting a forum should make plans so that an invitation can be formally extended at a future meeting. As of this writing, 1989 is the first unassigned year. (Illinois will host the 1987 meeting; Oregon will probably host the forum in 1988.)

PROFESSIONAL MEETINGS

Earth Remote-Sensing. Workshop, Flagstaff, Ariz., Nov. 4-8, 1985. Contact Geosat Committee, Suite 209, 153 Kearny, San Francisco, CA 94108; (415) 981-6265.

Artificial Recharge of Ground Water. Meeting, San Francisco, Calif., Dec. 9-13, 1985. Contact American Geophysical Union, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6903.

Computers in Mineral Exploration. Meeting, Toronto, Canada, Jan. 13-15, 1986. Contact T. J. Bottrill, 192 Weldon Ave., Oakvile, Ont., L6K 2H8.

Engineering Geology and Soils Engineering. Symposium, Boise, Idaho, Feb. 26-28, 1986. Contact Spencer H. Wood, Dept. of Geology and Geophysics, Boise State University, Boise, ID 83725; (208) 385-1631.

Geology and Ore Deposits of Arizona and the Southwest. Meeting and field trips, Tucson, Ariz., March 20-21, 1986. Contact University of Arizona Conference Dept., Rm. 3201, 1717 E. Speedway Blvd., Tucson, AZ 85719; (602) 621-1232.

Cordilleran Section, Geological Society of America. Annual meeting, Los Angeles, Calif., March 25-28, 1986. Contact Terry E. Davis, Dept. of Geology, California State University, Los Angeles, CA 90032; (213) 224-3388.

NEW BUREAU PUBLICATIONS

The following publications may be purchased over the counter or by mail from the Bureau offices at 845 N. Park Ave., Tucson, AZ 85719. Orders are shipped via UPS; street address is required for fastest delivery. All orders must be prepaid by check or money order made out to the Arizona Bureau of Geology and Mineral Technology. Shipping and handling charges are listed below. If your total order is

\$1.01 to \$5.00, add \$1.75	40.01 to 50.00, add 7.75
5.01 to 10.00, add 2.25	50.01 to 100.00, add 10.00
10.01 to 20.00, add 4.25	More than 100.00, add 10%
20.01 to 30.00, add 5.50	Foreign mail, add 40%
30.01 to 40.00, add 6.25	

BULLETIN

Welty, J. W., Reynolds, S. J., Keith, S. B., Gest, D. E., Trapp, R. A., and DeWitt, Ed, 1985, Mine index for metallic mineral districts of Arizona: Bulletin 196, 92 p.; \$7.00.

This index provides a county-by-county list of mines within Arizona's mineral districts, as defined in Arizona Bureau of Geology and Mineral Technology Map 18 and Bulletin 194. Approximately 5,500 mines are included. Two lists are given for each county: the first is a catalog of mines within each district; the second is an alphabetical cross-index of mines within the county. A mineral-district map of each county, at a scale of 1:1,000,000, is also presented. This index allows the explorationist to determine which mines are responsible for the metallic mineral production recorded in Bulletin 194.

OPEN-FILE REPORTS

Reynolds, S. J., and Spencer, J. E., 1984, Geologic map of the Aguila Ridge-Bullard Peak area, eastern Harcuvar Mountains, west-central Arizona: Open-File Report 84-4, 2 p., scale 1:24,000; \$1.75.

The Aguila Ridge-Bullard Peak area contains the Bullard detachment fault, a major normal fault that separates lower-plate chloritic breccia and mylonitic gneiss of the Harcuvar metamorphic core complex from an upper plate of highly tilted, Tertiary volcanic and clastic rocks. The Tertiary sequence includes welded ash-flow tuffs, sedimentary breccias, landslide-related megabreccias, and andesites that host copper-gold mineralization at the Bullard mine. This map identifies upper-plate faults and the Bullard detachment fault, which are locally altered and mineralized.

Reynolds, S. J., and Spencer, J. E., 1985, Reconnaissance geologic map of the Merritt Hills, southwestern Yavapai County, Arizona: Open-File Report 85-5, scale 1:24,000; \$2.00.

This reconnaissance map depicts the Precambrian plutonic and metamorphic geology of the small hills west of Congress Junction.

Spencer, J. E., and Welty, J. W., 1985, Reconnaissance geology of mineralized areas in parts of the Buckskin, Rawhide, McCracken, and northeast Harcuvar Mountains, western Arizona: Open-File Report 85-6, 31 p.; \$5.00.

This report is a catalog of brief descriptions of mines and prospects in most mineralized areas of the Buckskin and Rawhide Mountains, plus one mineralized area each in the McCracken and northeastern Harcuvar Mountains. The descriptions are based on new field observations. As a result of this field review, mineral-district assignments for several mines have been modified and updated.

Reynolds, S. J., Florence, F. P., Currier, D. A., Anderson, A. V., Trapp, R. A., and Keith, S. B., 1985, Compilation of K-Ar age determinations in Arizona: Open-File Report 85-8, 320 p.; \$24.00.

This report summarizes information from a computerized compilation of 1,214 published K-Ar age determinations in Arizona. Information compiled for each date includes material dated, rock type, name of rock unit, location information, and comments about the geologic setting and significance of the date. The ages are indexed by geographic area, geologic formation or rock unit, and original sample number. A complete list of cited references is included.

Spencer, J. E., Richard, S. M., and Reynolds, S. J., 1985, Geologic map of the Little Harquahala Mountains, west-central Arizona: Open-File Report 85-9, 18 p., scale 1:24,000, 3 sheets; text: \$3.00; map: \$3.00

The Little Harquahala Mountains are composed of a series of stacked thrust sheets that contain a diverse assemblage of rocks and structures. The lowest exposed rocks are Mesozoic volcanic and sedimentary rocks equivalent to the McCoy Mountains Formation and underlying Jurassic (?) volcanics. These units are structurally overlain by the Hercules plate, which is composed of Jurassic and Precambrian crystalline rocks. The Hercules plate is overlain by the Centennial plate, which contains Precambrian granitic rocks, a cratonic section of Paleozoic rocks, and Mesozoic volcanic and sedimentary rocks. The major structures have been intruded by the Upper Cretaceous Granite Wash Granodiorite and numerous middle Tertiary dikes. Mineralization in the area, including the bonanza gold ores of the Harquahala mine, is generally controlled by either thrust-related or post-thrusting structures.

Wright, P. L., Trapp, R. A., Reynolds, S. J., Richard, S. M., and Peirce, H. W., 1985, Theses and dissertations on Arizona geology, 1891-1978: Open-File Report 85-10, 141 p.; \$12.00.

This report contains a comprehensive list of theses and dissertations, completed between 1891 and 1978 on Arizona geology and related subjects. The compilation includes a main list of theses and dissertations, alphabetized by author, and two supplementary indexes. The first index is a statewide subject index, which lists the author, date, and physiographic-geologic province or provinces (Colorado Plateau, Transition Zone, or Basin and Range) encompassed by each thesis and dissertation. The second index lists the author and date of each thesis and dissertation by province, county, and specific geographic area (e.g., San Francisco volcanic field or Sunset Crater).

Spencer, J. E., Reynolds, S. J., Anderson, Phillip, and Anderson, J. L., 1985, Reconnaissance geology of the crest of the Sierra Estrella, central Arizona: Open-File Report 85-11, 20 p.; \$4.00.

A reconnaissance study of the crest of the northwest-trending Sierra Estrella in central Arizona indicates that this range is primarily composed of gneiss and schist with a steeply dipping, northeast-striking foliation similar to that in 1.6- to 1.7-b.y.-old metamorphic rocks found elsewhere in Arizona. Granitic rocks with a concordant foliation form sills and large intrusions into the schist and gneiss and are thought to be approximately the same age as metamorphism and deformation. Younger, weakly foliated to unfoliated granitic rocks are exposed at the south end of the range and correlate with the widespread 1.4-b.y.-old granite suite of North America.

Welty, J. W., Reynolds, S. J., and Trapp, R. A., 1985, Ore grades for metallic mineral districts of Arizona: Open-File Report 85-12, 34 p.; \$6.00.

This report presents the results of a computerized compilation of ore grades for metallic mineral production in Arizona. The grades for all recognized mineral districts are presented by county. Mineral districts have also been classified according to 10 distinct deposit types, and characteristic grades for each deposit type have been calculated. Variations in metal content within a single deposit type have been examined by normalizing production figures for each mineral district to the total production for all mines of that deposit type. Ore grades among different deposit types can be compared by normalizing production of each mineral district to total base- and precious-metal production in Arizona. The normalized data are then plotted on ternary diagrams with gold, silver, and total base-metal production as the apices.

Orlo Childs Retires from MMRRI

Dr. Orlo E. Childs, director of the Arizona Mining and Mineral Resources Research Institute (MMRRI) since 1980, retired as of June 30, 1985.

Dr. Childs brought to this position extensive experience in petroleum exploration, geologic research, teaching, and educational administration. He received his B.S. and M.S. degrees from the University of Utah and his doctorate in geology from the University of Michigan. He taught at Weber College, the University of Michigan, Colgate University, the University of Wyoming, and Texas Tech University. Dr. Childs served as a geologist for the Sinclair Wyoming Oil Company and as Exploration Projects Director for the Phillips Petroleum Company. In the latter position, which he held for 13 years, he planned and directed the work of 45 geologists in the United States, Canada, Central America, Australia, Algeria, and Libya.

Dr. Childs launched the research program in oceanography for the U.S. Geological Survey (USGS). He directed geologic studies of the Pacific and Atlantic continental-shelf environments from USGS offices in Menlo Park, Calif. and Wood's Hole, Mass., respectively.

In 1963 Dr. Childs was appointed the 11th president of the Colorado School of Mines. During his seven-year term, the school experienced rapid growth, program revision and enrichment, and expansion of industrial and private funding.

From 1970 to 1979, Dr. Childs served at Texas Tech University, 4 years as Vice President for Research and Special Programs and

5 years as "University Professor," one of only four such appointments. In the former position, he was responsible for research planning and operations; in the latter, he taught classes in educational administration, museum sciences, geology, and geography.

Dr. Childs has been involved in numerous public service and professional activities. He was a member of the Oil Shale Advisory Board appointed by the Secretary of the Interior to suggest policy on development of oil shale as a national resource. He has been a long-standing member of the American Association of Petroleum Geologists (AAPG) and was elected president in 1965 and honorary member in 1970. He was chairman of the Colorado section of the American Institute of Mining and Metallurgical Engineers (AIME). He served 5 years on the Advisory Council of the Public Land Law Review Commission.

While at Texas Tech University, Dr. Childs was the special institutional representative to the New York-based committee for U.S. participation in the United Nations University. He served as the only university representative in the General Technical Advisory Committee to the Office of Coal Research. He also served as chairman of the Energy Projects Council of the Gulf University Research Consortium of 14 universities in states surrounding the Gulf of Mexico.

In 1979 Dr. Childs was appointed an adjunct professor to the Arizona Bureau of Geology and Mineral Technology, University of Arizona, a position that he still holds today. He assumed the directorship of the MMRRI in 1980 and now holds the title of Emeritus Director. For the last 6 years, Dr. Childs has directed a monumental AAPG research project known as Correlations of Stratigraphic Units of North America (COSUNA). This project involved 450 volunteer contributors from all parts of the Nation. Dr. Childs will continue to direct the COSUNA project during his semiretirement.

Call for Radiometric Age Determinations in Arizona

The Arizona Bureau of Geology and Mineral Technology has established a computerized database of all K-Ar, Rb-Sr, U-Pb, and fission-track age determinations in Arizona (see "New Bureau Publications," this issue). This compilation will be published as a Bureau bulletin containing two sections: (1) the compilation; and (2) a series of separately authored, short articles, extended abstracts, and data that report and interpret previously unpublished age determinations. All persons with unpublished age determinations are asked to contact Stephen J. Reynolds at the Bureau.

Fieldnotes

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University of Arizona .... President Henry Koffler
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