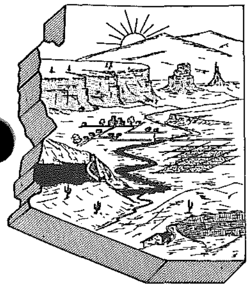

FIELDNOTES
From The State Of Arizona
Bureau Of Geology And Mineral Technology

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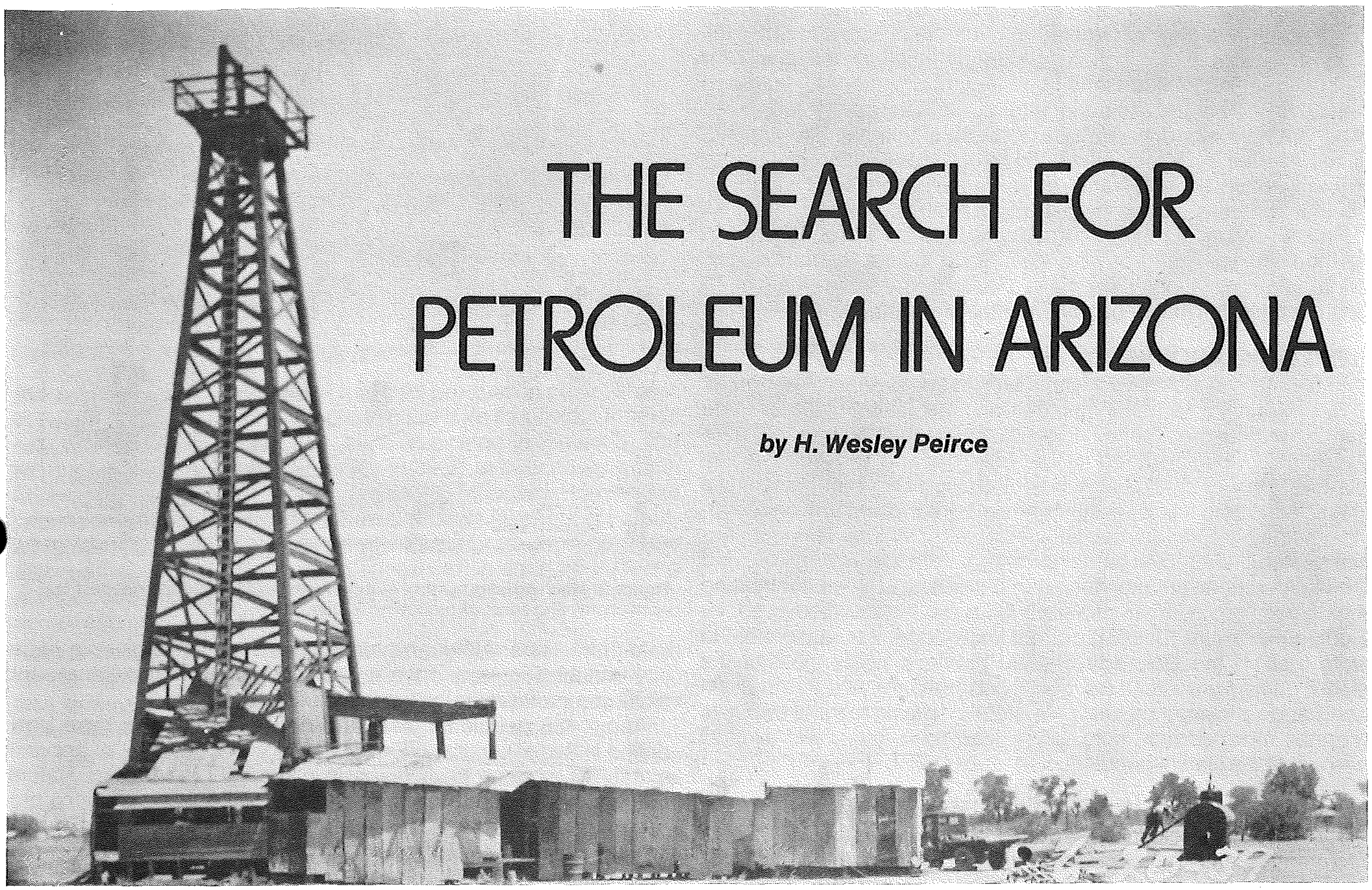

THE SEARCH FOR PETROLEUM IN ARIZONA

by H. Wesley Peirce

Phoenix drilling venture. Hole located between 24th and 32nd St., north of Van Buren and east of State Hospital. Hole abandoned at 1,600 feet due to lack of funds (1939). Photo: Elvin E. White.

INTRODUCTION

Although E. L. Drake drilled the first oil well in western Pennsylvania in 1859, it wasn't until the turn of the century that the incessant search for oil started. It began with the development of the internal combustion engine and the arrival of the age of gasoline. With the drilling of an oil exploration test hole in 1903, Arizona territory became a part of the search terrain. Subsequently, a relatively low-level, spasmodic exploration effort has continued within the state (Figure 1). Some of the highlights of this search, and associated discoveries, are reviewed here.

It is often said that the search for petroleum (crude oil and natural gas) begins in the mind, that drilling is the culmination of the search and not the beginning. Because ideas often go unrecorded, the most tangible, recoverable record of petroleum exploration is the drillhole. An idea may result from either a casual effort or a lengthy process of sophisticated geologic investigation, and the mere existence of a drillhole suggests little about the thought behind its placement and depth. Ideas change through time as

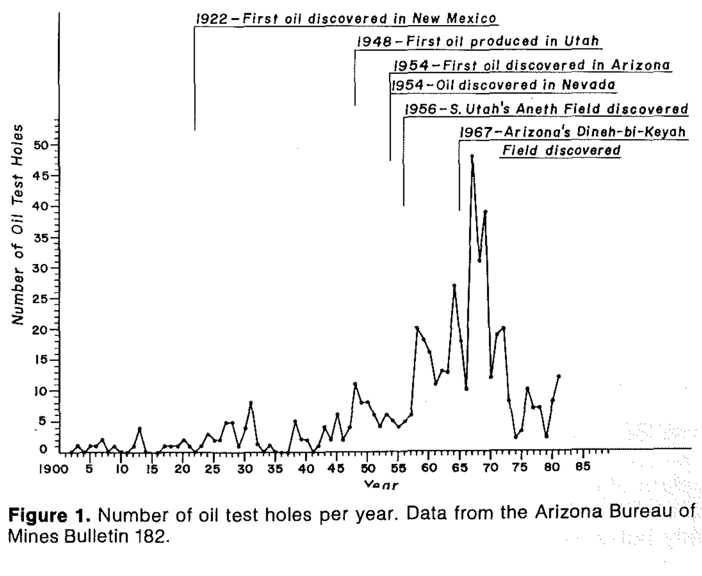

Figure 1. Number of oil test holes per year. Data from the Arizona Bureau of Mines Bulletin 182.

geologic understanding evolves. Exploration and drilling techniques also change, and these activities are becoming increasingly expensive, necessitating a judgment as to how much effort can be supported by available financial resources. In this regard, the price of petroleum products has a major influence on incentive. The search for petroleum is a costly, high-risk venture and easily discourages the pessimistic and the timid. The old adage "nothing ventured nothing gained" certainly applies to the business of discovering significant petroleum resources.

Although the physical record of holes drilled in Arizona, in the pursuit of petroleum resources is very good, the reasoning behind the placement and depth of each hole is often obscure, especially when reviewed at a later date. At the time of drilling, rumors tend to be rampant and care is required if, during later assessment, truth is to be separated from fiction. Frequently, a hole is drilled and, for technical or financial reasons, is abandoned short of its intended objective. In such cases the original idea is not tested, even though a hole was drilled. Thus, because a hole has been drilled, is not in itself sufficient reason to reject reevaluation of the petroleum potential of the same area. Reevaluation is an unending, constant process among the petroleum hunters.

The following comments about the search for petroleum in Arizona are very general and cannot do justice to the thought, effort, time, and money that have been invested over the last 79 years in attempts to find petroleum within the state.

GEOLOGIC PROVINCES

The state of Arizona consists of almost equal parts of two major U.S. physiographic provinces: 1) Colorado Plateau to the northeast, and 2) the Basin and Range country to the southwest (Figure 2). Actually, the dividing line between the two provinces is the northwest-trending, 300-mile-long Mogollon Rim that bisects the state. Although traditionally referred to as physiographic provinces, they are, fundamentally, geologic provinces. Their respective geologic characteristics are as different as night and day, and these differences are manifested in a diversity of ways,contrasting rock types, geologic structures, and known natural resources, including petroleum. Utilizing current knowledge, it is reasonable to state that: 1) the Colorado Plateau province holds most of the state's energy resources (oil, gas, coal, uranium), and 2) the Basin and Range province contains the state's metallic mineral deposits (copper, molybdenum, gold, silver, lead, zinc, etc.), and over 93 percent of the state's population.

FUNDAMENTALS OF PETROLEUM OCCURRENCE

The prevailing scientific wisdom is that petroleum is formed in sedimentary environments that contain abundant organic matter capable of being transformed into petroleum. Once formed, petroleum fluids must accumulate in large amounts if they are eventually to be exploited by wells. Oil and gas (being fluids) move, under the influence of pressure gradients, through rocks via natural plumbing systems. Such migration can lead to dispersion and loss or to concentration in some type of geologic trap. Often, the trap is a domal structure which is detectable at the earth's surface or in the deep subsurface by geophysical techniques. Most of the surface structures have been drilled, but it is the elusive 'blind' subsurface structures that are presently being sought. The search is more costly than ever and tends to discourage the "little guy."

Although petroleum is believed to have been derived from sedimentary rocks, it can, after migration, collect in any rock type having appropriate physical properties, especially open space. This fact complicates the search in geologically complex regions because exotic occurrences are very difficult to find.

THE SEARCH IN ARIZONA

Records indicate that the first oil exploration hole in Arizona (before statehood) was drilled to a depth of 2,003 feet in Chino Valley (Yavapai County), north of Prescott in 1903. Many of the early holes were drilled by promoters who raised capital by the

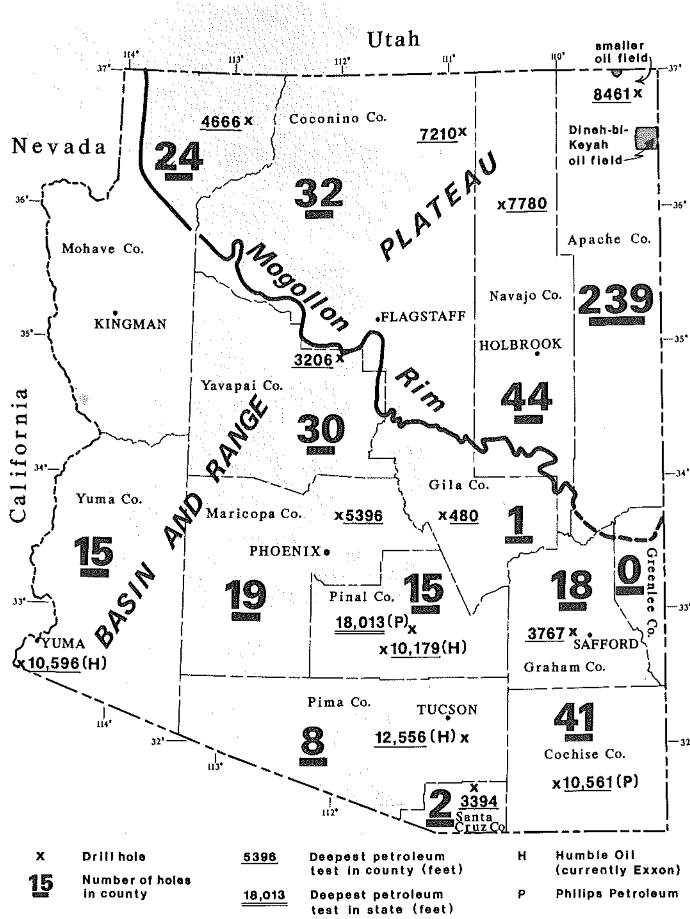

Figure 2. Map showing number of petroleum tests by county; deepest test in each county and state; oil producing region.

sale of interests. Although promotion is sometimes given a negative connotation, very often it is the only way for individuals and small companies to raise money for risky ventures.

About 488 petroleum tests and development wells have been drilled in Arizona to date (Figure 2). Sixty-five of these, or approximately 13 percent, have resulted in some oil production. Natural gas has been found only in relatively small quantities. All oil production has come from a tiny part of northeastern Arizona on the Navajo Indian Reservation where tribal policy controls all exploration ventures (Figure 2). The policy has been to have a lease sale on high-interest lands so that drilling rights go to the highest bidder, a procedure that limits participation to relatively well-financed companies. Lesser entities generally find it necessary to explore on non-tribal lands, a restriction that affects the search for petroleum in Arizona, in that it significantly reduces the chance for "accidental" discovery. (There is still an element of luck behind most mineral and energy resource discoveries).

More than 120 exploration holes were drilled in the state before the first oil find in 1954 by Shell Oil Co. (Figure 1). The resulting field, the Boundary Butte field, is small and adjacent to the border with Utah. Additional small fields were developed in the Arizona portion of the Four Corners region. Then, in 1967, Kerr-McGee drilled their discovery hole in the Dineh-bi-Keyah field (Navajo name for "peoples' field") (Figures 1–4). A total of 33 productive wells have been completed in this unusual oil field. It is unusual in that the reservoir rock is igneous. The wells are situated atop the Lukachukai Mountains among pine trees at elevations of 7,000-8,000 feet (Figure 3). The productive horizon is less than 3,000 feet below the surface.

By the end of 1981, 18,113,666 barrels of oil had been produced in Arizona, 16,141,285 barrels* (89 percent) of which was from

***Data from the AZ Oil and Gas Conservation Commission (1981).**

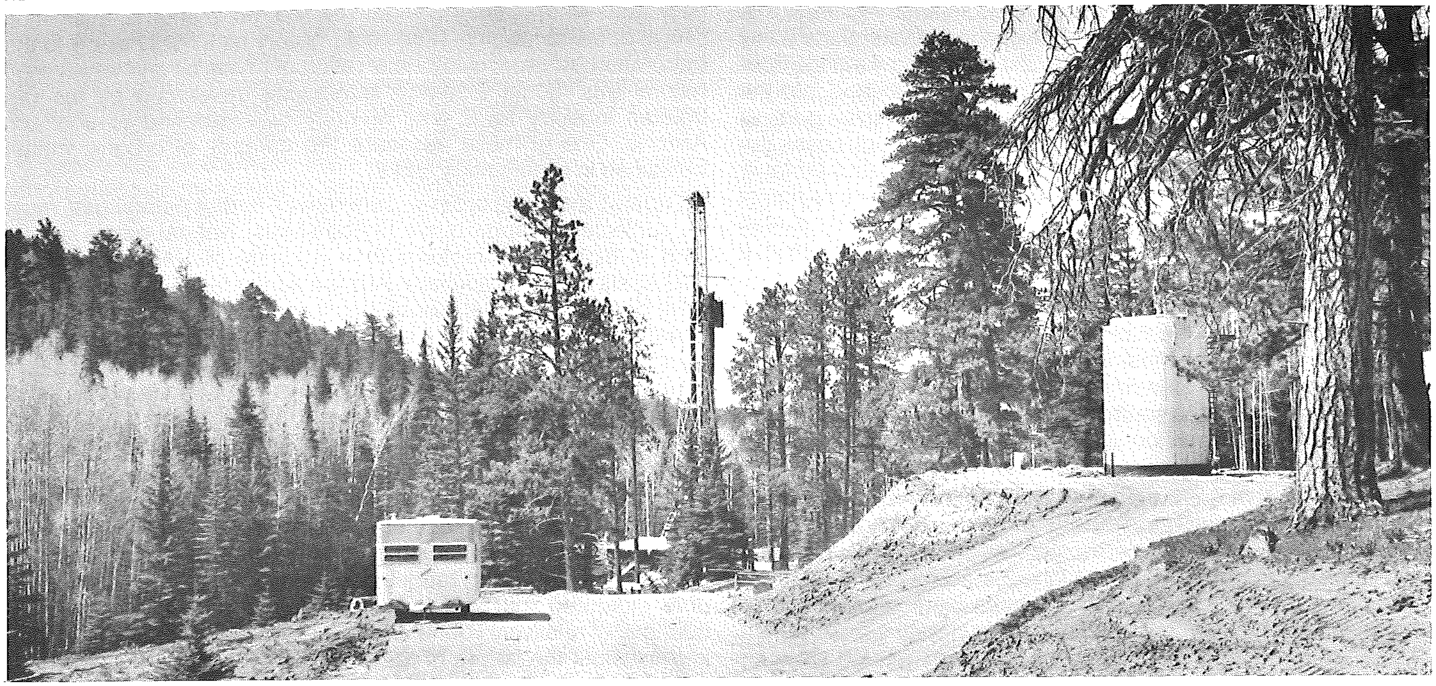

Figure 3. Drilling in Dineh-bi-Keyah field, Navajo Indian Reservation, Arizona (1968). Photo: H. Wesley Peirce.

Dineh-bi-Keyah (Figure 5). Thus the state production curve, shown in Figure 5, largely reflects the production from this field. Oil fields naturally decline in production, as is illustrated in Figure 5. The production high point was reached in 1968 at over three million barrels; by 1981 production was down to 357 thousand barrels per year, a ten-fold decrease. The state's proven reserves are dwindling because there has been no significant production from new discoveries. The national trend is similar in that oil is being pumped at a faster rate than it is being replaced through discovery of new sources.

As previously noted, oil production is restricted to a small portion of northeastern Arizona adjacent to Four Corners. There has been less drilling and no production from the southwestern half of the state, i.e., the Basin and Range portion.

It has been emphasized that Arizona's geologic framework is one of major contrasts. The Colorado Plateau to the northeast, in three dimensions, is dominated by sedimentary rocks that are but slightly deformed by folding and faulting, and range in thickness between zero and about 9,000 feet. Under these circumstances, if petroleum ever existed in the buried strata, its chance for preservation is excellent. However, Arizona's Basin and Range country to the south is characterized by a complex sequence of rock units that have been severely faulted, folded, and subjected to elevated temperatures. Under these circumstances, even if oil survived the various structural and thermal events, points of concentration would be difficult to anticipate. Consequently, it is the Plateau that has received the largest share of attention and, thus far, contains the only known crude oil reserves in Arizona and only small amounts of natural gas.

The three- dimensional geologic framework of Arizona's Plateau region varies significantly from place to place, in accordance with variations in geologic history and associated processes (see Reynolds, 1982). The end result is a spectrum of oil potential that ranges from nearly impossible to good. One of the guiding principles in petroleum exploration has been to stay away from areas with an igneous history. Ironically, Arizona's largest oil field, Dineh-bi-Keyah, as already noted, has an igneous rock as a reservoir. However, circumstances surrounding this occurrence are not well understood. The problem is one of petroleum migration timing.

Most of the oil potential of northern Arizona is related to about 4,000 feet of Paleozoic-age strata (230–570 m.y. ago). Although

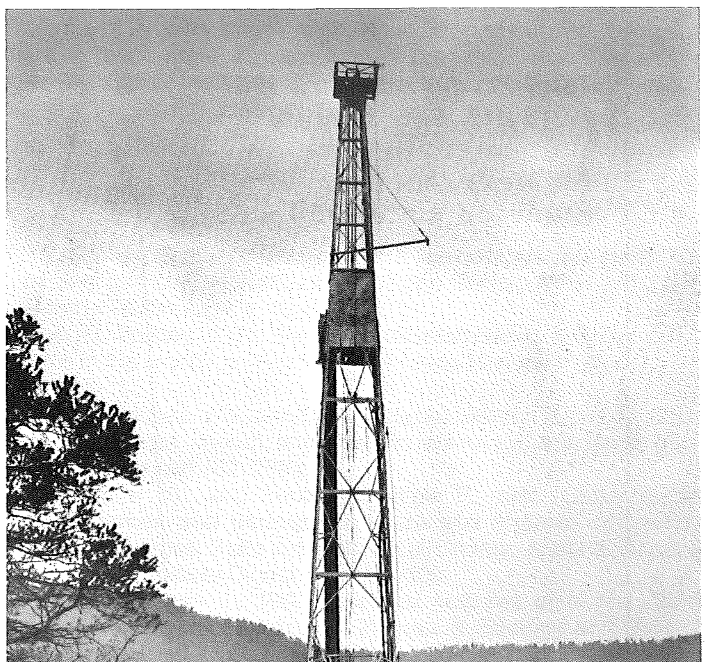

Figure 4. Close-up of drill rig (1968), Dineh-bi-Keyah field, Navajo Indian Reservation, Arizona (note sign, lower left corner). Photo: H. Wesley Peirce.

the walls of the Grand Canyon consist of sedimentary rocks of this age, significant lateral changes in rock character take place away from it. For example, although the specific source-rocks in the Four Corners region are Paleozoic in age, they do not extend into the Grand Canyon. This is easily explained by the fact that the particular sea involved in source-rock accumulation did not cover the Grand Canyon region. Also, the canyon itself is a negative factor in petroleum preservation because, not only does it allow a region of indefinite size to be drained of any hydrocarbon fluids, it also lowers subsurface pressures over a much larger region than it occupies.

The sea that produced the source rocks for the Four Corners country covered just a small portion of extreme northeastern Arizona and it is this part that is reponsible for most of Arizona's petroleum production. However, other marine rocks do occur, as in the Holbrook region to the south, and they provide some petroleum potential away from the Four Corners area. In recent years the leasing activity in the Holbrook country has picked up.

Whereas much of the Colorado Plateau country is a rather conventional setting in which to search for oil, the Basin and Range province of southern Arizona is "frontier" all the way. This province is ore-deposit country where past igneous activity, structural deformation, and elevated rock temperatures were relatively commonplace. As a consequence, the geologic literature on southern Arizona is dominated by the observations of geologists who specialized in the search for ore deposits, not oil pools. Observations of rock characteristics of critical importance to petroleum geologists were often not made. This has led to another evaluation phase of the fundamental geologic history as it might apply to the generation, storage, and preservation of crude oil and associated natural gas. Some research techniques developed by the petroleum industry have only recently been applied to southern Arizona. One of these assesses the maturity of organic matter contained in sedimentary rocks.

Organic matter, in order to generate oil and/or natural gas, must be subjected to appropriate temperatures. Natural gas is generated at higher temperatures than is crude oil. Many petroleum geologists think that southern Arizona subsurface thermal regimes have been so high that natural gas is more likely to occur than oil. However, there are others who think that because temperatures were so high, the likelihood of preserving either oil or natural gas is minimal. This may be true for petroleum that is related to rocks affected by a particular thermal event, of which there have been several in southern Arizona. What about rocks that post-date most of the severe thermal activity?

It was this line of thinking that brought Humble Oil and Refining Co. (now Exxon) into southern Arizona in 1971. The Basin and Range province takes its name from the present topographic appearance of alternating ranges and valleys. Knowledge then available indicated that valleys were often underlain by thick sequences of relatively young and diverse strata. However, little was known about the nature of these rocks at depth. The question of marine vs. non-marine was not critical because the famous oil shales of Colorado are non-marine in origin. Such rocks would

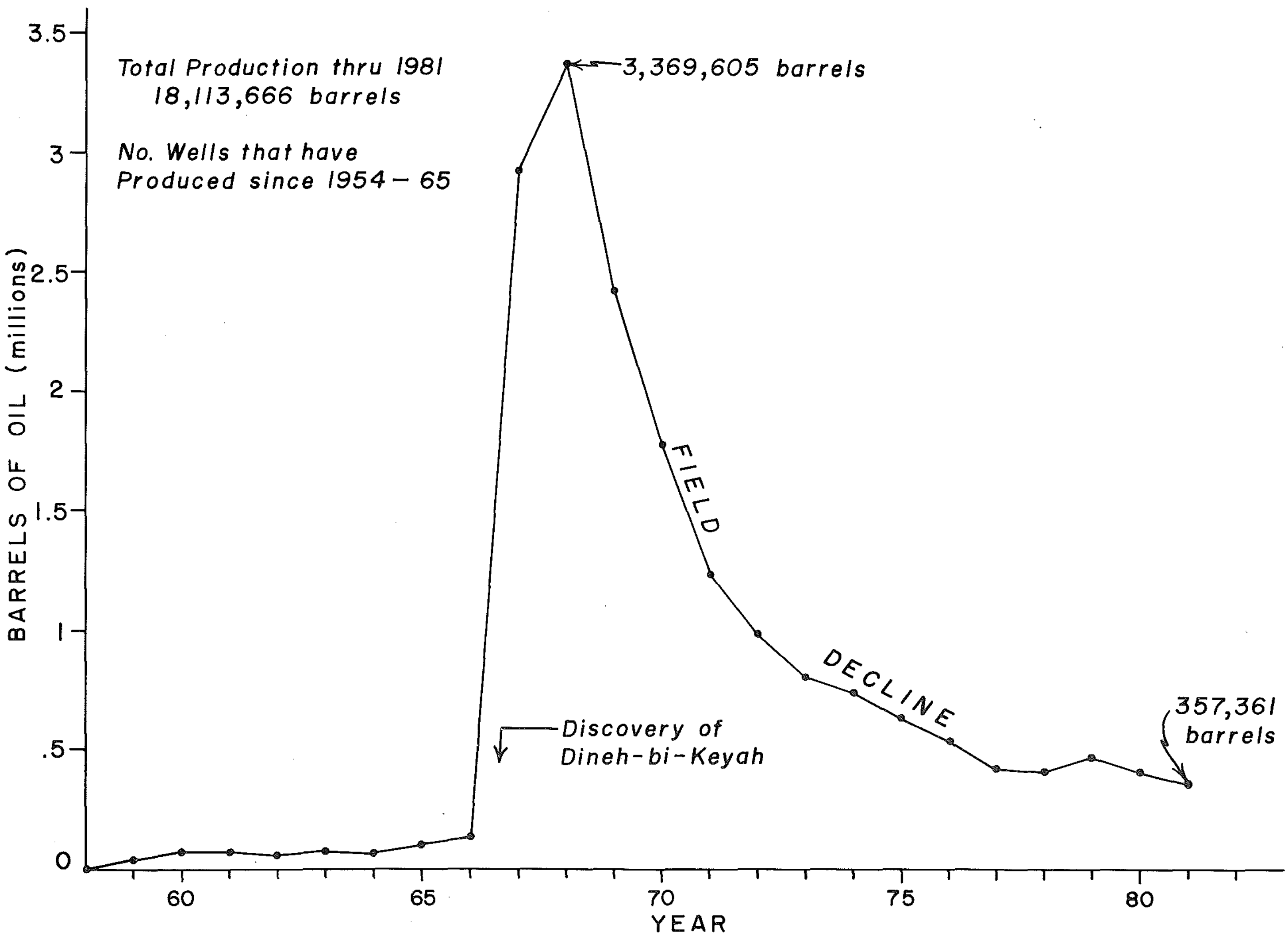

Figure 5. Annual oil production in Arizona (1953–1981). Data from the Arizona Oil and Gas Conservation Commission.

serve as adequate sources but not reservoirs. The size of some of the basins also indicated that volumes of contained sediment could be enough to generate significant amounts of petroleum, providing that the original environments of sediment accumulation afforded sufficient organic matter from which hydrocarbons could be generated. In addition, there was the possibility that certain other hydrocarbon-rich rocks, young enough to have escaped severe thermal disruption, could underlie the deeper parts of the valleys. Such rocks are known in several southern Arizona ranges, including the Tucson Mountains near Tucson. Humble drilled four holes totaling 36,850 feet, after leasing much of an 18,000-square-mile swath of Arizona desert (from Mexico to California) and conducting surface geologic studies and seismic surveys designed to provide information on rock arrangements at depth. Although this effort provided much information about how Arizona is put together, no significant petroleum was encountered. This project was bold, imaginative, and theoretically sound. It demonstrated that even though the young sediments were thick (on the order of thousands of feet), they were not organic-rich, at least where drilled (Figure 2).

After the Humble effort, interest waned in the Arizona Basin and Range province. Then, in 1978, another idea invaded the media—the concept of an "overthrust belt" through southern Arizona. Again, almost all leaseable land was picked up, especially inexpensive state lands. The overthrust hypothesis, as espoused by the principals in this promotion, was presented in *Fieldnotes* (Keith, 1980). It held, in part, that about 60 million years ago, older granitic rock that now characterizes a northwest-southeast-trending belt (including Phoenix and Tucson) through the Basin and Range province, was shoved (thrust) over younger, possibly oil-related strata. Certain seismic patterns were interpreted to represent sedimentary rocks having a domal form at depth, beneath granitic rocks known to be at or near the earth's surface. The only way to test the idea was to drill.

Late in 1980, what was destined to become the deepest probe to date into Arizona's mysterious region of "down" was started. Several months and about 12 million dollars later, the exploration test was terminated at 18,013 feet. Below the granite, layered sedimentary rocks were not encountered, only other igneous and metamorphic rocks. The seismic reflections proved to be a response to the internal characteristics and structures associated with these rock types. Three major rock bodies were encountered, and the interpretation of their relationships and significance has been discussed (Reif and Robinson, 1981). The final geologic significance of this test will remain in doubt until more is learned about the complexities of crystalline rock (granitic and metamorphic) geology in southern Arizona. The data from this hole remain equivocal as to the presence or absence of significant thrusting. It is a problem in interpretation.

Related to this "overthrust" venture is a hole near Tombstone drilled to about 10,000 feet by the same interests that drilled the Florence hole—Phillips Petroleum Co., Anschutz Corp., and Peoples' Energy. Engineering problems apparently caused premature abandonment, thus rendering the test inconclusive. Although geologic analysis of this test has yet to be released, some information is available. The hole was terminated in sedimentary rocks of suspected Cretaceous age, at a depth of 10,561 feet. Older rocks are believed to occur higher in the hole, suggesting that faulting has placed these older rocks (granite and limestone) over the younger rocks. The nature of the faulting has yet to be evaluated. Phillips Petroleum is planning to drill at least six additional holes designed to gather basic geologic information in southern Arizona; three of these are completed, two are being drilled, and one is planned.

Thus far, southern Arizona continues to be ore-deposit country, not petroleum. Petroleum very likely existed here prior to a series of disruptive geological events that may have dispersed much preexistent oil and/or natural gas. Some petroleum could remain, perhaps in highly unusual places, but finding it is proving elusive and costly.

Meanwhile, periodic drilling takes place in the Plateau country. Most recently, activity has centered north of the Grand Canyon near the Utah-Arizona boundary. Here, known oil seeps are constant reminders that hydrocarbons have been around. However, many of these are from surface rocks not sufficiently buried to contain oil of high fluidity and under sufficient pressure to make them flow and concentrate in traps.

Arizona possesses oil in its Plateau country, and most likely, there is more to be found. On the other hand, the southern Arizona Basin and Range country continues to be a scientific "frontier" and is not giving up its secrets easily.

An extensive overthrust zone is known to exist from Alaska to Mexico. However, its continuity is broken from place to place; one of the larger breaks involves most of southern Arizona where geologic complexity obscures the clear delineation of such a zone, if one ever existed. Intense exploration for petroleum in the western overthrust belt, since 1975, has resulted in substantial discoveries in the Wyoming-Utah region. This play was extended to Arizona where advantage was taken of relatively low-cost leases, especially on state-owned lands. This activity spawned renewed interest in southern Arizona and resulted in an intensive reexamination of its basic geologic framework. Although the information gained is invaluable and will be applicable in diverse ways for years to come, the case for petroleum occurrence in the Basin and Range province of Arizona seems not to have been enhanced. However, there is much more to learn than is presently known about the region. A good idea could lead to another flurry of exploration activity. The search goes on.

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GRAVITY MAPS

The Complete Residual Bouguer Gravity Anomaly Map has been completed in two scales. The 1:250,000-scale, two milligal contour interval map was produced by Dr. C.L.V. Aiken of the University of Texas (Dallas), under contract to the Geothermal Group of the Bureau of Geology and Mineral Technology (DOE contract #DE-FC07-79ID12009). This map is open filed at the Bureau (Report #81-24) and may be copied through local blueprint services. (Contact blueprint company directly for pickup, delivery and payment). The 1:500,000-scale map, prepared by Joseph C. Lysonski, C.L.V. Aiken, and John S. Sumner, is available from the Geophysical Society at the Department of Geosciences, University of Arizona for $25.00 (blue or blackline print).

HYDROLOGIC STUDIES IN ARIZONA

by Michael R. Long **Supervisor, Basic Data Unit**
Arizona Department of Water Resources

The Arizona Department of Water Resources (ADWR) and the U.S. Geological Survey (USGS), through a cooperative agreement, are responsible for hydrologic data collection for the State of Arizona. The data collection efforts include two programs—surface water and ground water.

The surface water data collection program is designed to monitor streamflow quantity and quality and includes operation and maintenance of more than 200 gaging stations on streams and rivers throughout Arizona. The ADWR shares the costs of 65 of these stations with the USGS. The remaining gaging stations are maintained through similar agreements between USGS and other state, county, and federal agencies.

Stream gage data are gathered to provide current and long-term streamflow data, used in the planning and management of storage reservoirs and the forecasting of floods. Streamflow data are used by the managing agencies responsible for storage reservoir operation (e.g., Salt River Project and San Carlos Irrigation District) to maintain the maximum storage possible along the major river systems in Arizona. In addition, 41 of the gaging stations are equipped with satellite telemetering equipment to provide data for flood forecasting. The ADWR and USGS have also cooperated in establishing a direct readout ground station in Phoenix, making flood flow data available more quickly and improving Arizona's flood warning capabilities. The data gathered in the surface water program are published in the USGS report series, "Water Resources Data for Arizona."

The ground-water data collection program includes three elements: 1) annual statewide ground-water monitoring program, 2) ground-water basin study program, and 3) research of specific hydrologic problems. The ADWR and USGS share the cost of these studies.

The statewide monitoring program is operated by the USGS and includes measuring water levels in selected monitoring wells and gathering ground-water pumpage data throughout the state. The data collected for the annual monitoring program are published annually, in map form, in a USGS open-file report titled, "Annual Summary of Ground-Water Conditions in Arizona."

The ground-water basin studies, formerly conducted by the USGS, have been conducted by the ADWR since 1979. These studies include comprehensive investigation of selected Arizona ground-water basins on a rotating basis. Data are collected in each basin every five to eight years to provide an overview of ground-water conditions of each basin. The comprehensive investigations include well site inventories for all major production wells, and water-level measurements and water-quality analyses in selected wells. The data collected in the ground-water basin

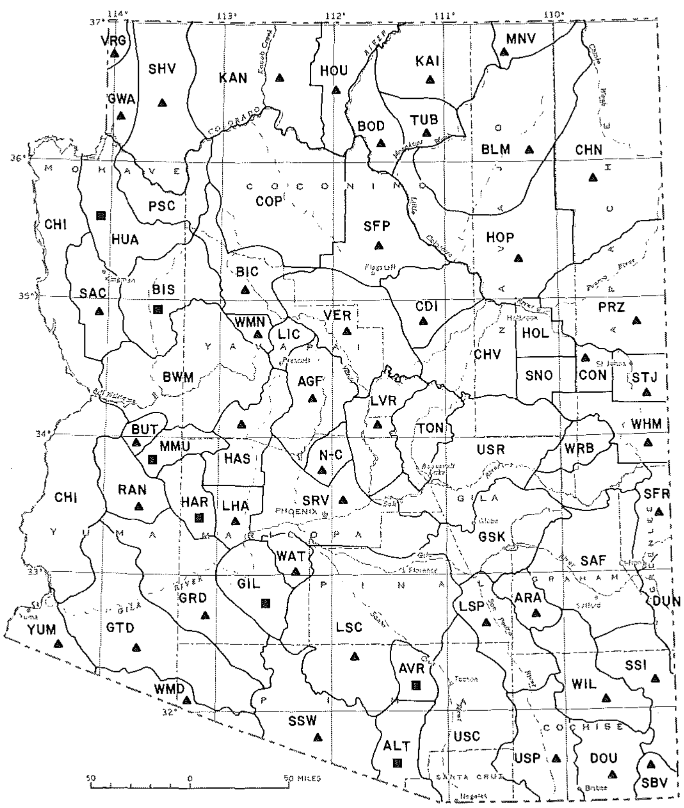

Figure 1. Map of areas investigated in Arizona.

■ Report published by the Arizona Department of Water Resources

▲ Report published by the U.S. Geological Survey

Blank indicates report not yet published

AREAS AND ABBREVIATIONS

AGF—Agua Fria basin
ALT—Altar Valley
ARA—Aravaipa Valley
AVR—Avra Valley
BIC—Big Chino Valley
BIS—Big Sandy Valley
BWM—Bill Williams
BLM—Black Mesa
BRB—Black River basin
BOD—Bodaway Mesa
BUT—Butler Valley
CDI—Canyon Diablo
CHV—Chevelon
CHN—Chinle
COP—Coconino Plateau
CHI—Colorado River (Hoover Dam to Imperial Dam)
CON—Concho
DOU—Douglas basin
DUN—Duncan basin
GIL—Gila Bend basin
GRD—Gila River drainage (Painted Rock Dam to Texas Hill)
GSK—Gila River (head of San Carlos Reservoir to Kelvin)
GTD—Gila River (Texas Hill to Dome)
GWA—Grand Wash
HAR—Harquahala Plains
HAS—Hassayampa basin
HOL—Holbrook
HOP—Hopi
HOU—House Rock
HUA—Hualupai Valley
KAI—Kaibito
KAN—Kanab
LIC—Little Chino Valley
LHA—Lower Hassayampa
LSP—Lower San Pedro basin
LSC—Lower Santa Cruz basin
LVR—Lower Verde River
MMU—McMullen Valley
MNV—Monument Valley
N-C—New River-Cave Creek
PSC—Peach Spring Canyon
PRZ—Puerco-Zuni
RAN—Ranegras Plain
SAC—Sacramento Valley
SAF—Safford basin
SRV—Salt River Valley
SBV—San Bernardino Valley
SFP—San Francisco Peaks
SFR—San Francisco River basin
SSI—San Simon basin
SSW—San Simon Wash
SHV—Shivwits
SNO—Snowflake
STJ—Saint Johns
TON—Tonto basin
TUB—Tuba City
USR—Upper Salt River basin
USP—Upper San Pedro basin
USC—Upper Santa Cruz basin
VER—Upper Verde River
VRG—Virgin River
WAT—Waterman Wash
WMD—Western Mexican drainage
WHM—White Mountains
WRB—White River basin
WIL—Willcox basin
WMN—Williamson Valley
YUM—Yuma

studies are currently published in the ADWR report series, "Hydrologic Map Series Reports." Previously, the data were published in the USGS open-file report series, "Water Resources Investigations." Six reports have been published as Hydrologic Map Series reports and 45 basin study reports have been published as Water Resources Investigation reports since the program began. The most recent example is a report entitled, "Maps Showing Ground-Water Conditions in the McMullen Valley Area, Maricopa, Yavapai, and Yuma Counties, Arizona."

ADWR staff are currently studying the Little Chino Valley (LIC), Waterman Wash area (WAT), Lower Hassayampa area (LHA), the Upper Santa Cruz area (USC), Avra and Altar Valleys (AVR/ALT), and the Salt River Valley (SRV).

Research on specific hydrologic problems is conducted by the USGS and ADWR. The research includes site-specific studies and interpretive analysis of hydrologically complex areas of the state. The research may include geologic mapping, well inventory, detailed water-level data collection, detailed water-quality monitoring, digital ground-water modeling, geophysical investigations, and exploration drilling programs. The results of the research and the data collected are published in the ADWR bulletin series. To date, eleven bulletins have been published; most were published as Arizona Water Commission (AWC) bulletins (AWC was ADWR's predecessor). The latest report in this series is entitled "Water Resources in the Sedona Area, Yavapai and Coconino Counties, Arizona."

For information on ADWR publications, contact the Arizona Department of Water Resources, Basic Data Unit, 2810 South 24th Street, Suite 122, Phoenix, Arizona 85034. For information on USGS publications, contact the U.S. Geological Survey, Federal Building, 301 West Congress, Tucson, Arizona 85701.

NEW STAFF

George H. Davis has been selected to be the new chairman of the Department of Geosciences at the University of Arizona (Tucson) in July 1982, after having taught 12 years at U of A. Dr. Davis replaces Edgar J. McCullough, Jr., department head for 12 years.

L. Paul Knauth is the new chairman of the Department of Geology at Arizona State University in Tempe (July 1982). Dr. Knauth has been with the university since 1979 and follows David Krinsley, the former department chairman (1976–1982).

Michael Morales has been appointed Curator of Geology at the Museum of Northern Arizona, Flagstaff. Dr. Morales will leave the University of California at Berkeley to join NAU staff in September 1982.

David W. Thayer is the newly appointed Curator of Earth Sciences at the Arizona-Sonora Desert Museum (March 1982). Founder of two of Arizona's three speleological organizations, Thayer has taught geology at Yavapai College in Prescott since 1974.

STATE/REGIONAL EVENTS

Museum of Northern Arizona—35th Annual Geology Symposium, Flagstaff, August 27, 1982.

Denver Region Exploration Geologists Society—Meeting, Genesis of Rocky Mountain ore deposits, Denver, November 4–5, 1982.

ANNOUNCEMENT

The following information may be added to the 'Federal Agencies In Arizona' listing in the March 1982 issue of Fieldnotes.

The U.S. Forest Service employs personnel dealing with earth science-related matters—geology, minerals, and mining—on forest lands. These services are maintained at a zone office in Phoenix at 522 N. Central Ave., Room 202, Phoenix, Arizona 85004 (602/261-4372).

Orbicular Rocks Near Kingman

by Howard L. Stensrud
Professor of Geology, Department of Geology and Physical Science, California State University, Chico, California

A small outcrop of igneous rock displaying orbicular structures has been located near Kingman, Arizona, the second known occurrence in the state. The orbicular rock was discovered during field work related to a NSF-funded regional geologic study of the west-central Hualapai Mountains (see Stensrud and More, 1980). Orbicular rocks contain orbicules which consist of a central core surrounded by one or more concentric shells. They are uncommon, unusual, and petrographically distinctive (see Figure 1). One theory holds that orbicular rocks represent some kind of inclusion in magma, that these igneous rocks formed when reacting with the melt. Orbicular rocks sporadically occur in limited areas throughout the world. A review paper of world-wide occurrences, descriptions, and proposed modes of origin for orbicular structures was published by Leveson (1966). At that time there was one known occurrence of orbicular rocks in Arizona, near Tucson.

The orbicular structures south of Kingman are in a 100-by-200-foot area within altered andesitic dike-rock of uncertain age, located about .1 mile east of the ATSF railroad tracks in the NW¼ sec. 4, T. 20 N., R. 17 W., Kingman, Arizona 7½ minute quadrangle. Hydrothermally altered, coarse-grained granite of Precambrian age crops out nearby.

The orbicules are small (.5 to 1.5 cm across), irregularly spaced, and comprise 5-10 percent of the rock (Figure 1 is volumetrically atypical). Most orbicules contain a single shell of granular texture, 1-2 mm thick, surrounding a core which is texturally and compositionally dissimilar to the matrix. An unusual and possibly unique aspect of the Kingman orbicules is the occurrence of up to 20 percent fluorite within the orbicule shell, and lesser, but recognizable amounts in the cores.

This occurrence should be added to the list of interesting and unusual rocks that occur in Arizona.

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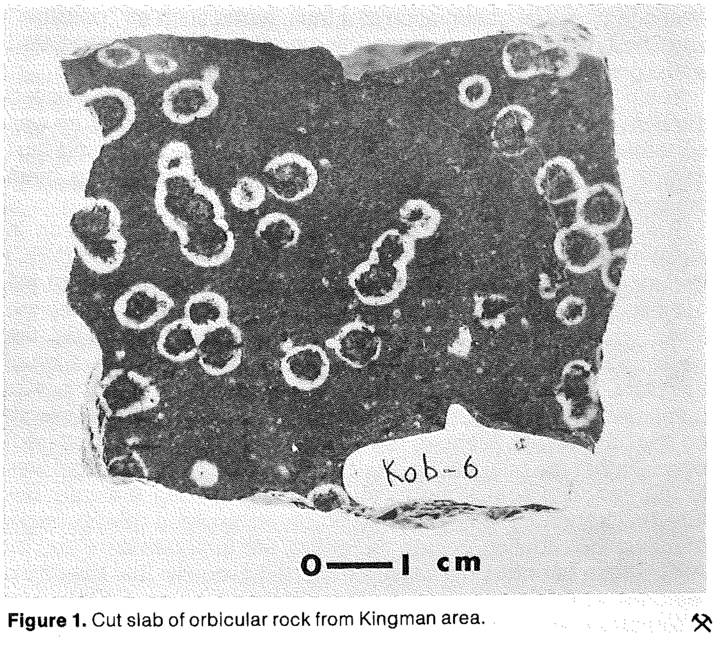


Figure 1. Cut slab of orbicular rock from Kingman area.

Figure 1. Aerial view of one of the scarp like features in the Hassayampa area (May 25, 1982). Photo: Christopher Menges.

Scarp Features—not young faults

by H. Wesley Peirce

In June 1982, media publicity was given to some geologic features located about 10 miles northeast of the Palo Verde Nuclear Power Plant. These features, called scarps, were encountered by Christopher M. Menges, Research Geologist at the Arizona Bureau of Geology and Mineral Technology, in connection with a statewide study of young faulting in the state. This study, financed by the U.S. Geological Survey, made use of high-altitude U2 aerial photography and subsequent field investigations of possible young fault-related phenomena identified in the photos.

The best evidence for young faulting (within the last 1-2 million years) is to actually *see* a fault plane cutting young geologic materials. Normally, faults cutting young material cannot be seen directly because of modifications rendered by subsequent erosion and deposition. Consequently, proving the existence of a young fault usually requires trenching to produce a fresh exposure. In the absence of actual observation of a fault, terms such as "possible" and "probable" are used, depending on the evidence associated with a given land form feature.

In the present case, Menges made aerial photographs, visited the site on the ground, and flew over it. From these studies he was not able to convince himself that the scarps were not young fault scarps. As a consequence, he classified them as having been caused by "possible" faults.

The Bureau of Geology and Mineral Technology has been in close contact with the U.S. Nuclear Regulatory Commission (NRC) throughout the site investigation and construction phases of the nuclear plant. After determining his findings, Menges informed the NRC, which, in turn, notified Arizona Public Service (APS), the company responsible for the safety, construction, and operation of the plant. The company's geological consultant, John Scott, was contacted by APS. Scott flew over the scarp site and then visited it on the ground with Menges. Their opinions differed and both recognized that the only way to solve the question of scarp origin was to dig trenches across the most suspicious looking features. Before the trenching was done, APS issued a press release summarizing the situation. Shortly thereafter, two trenches were dug by APS. These trenches demonstrated, unequivocally, that the scarp features were not caused by faulting. Rather, they were caused by a complex combination of erosional and depositional processes.

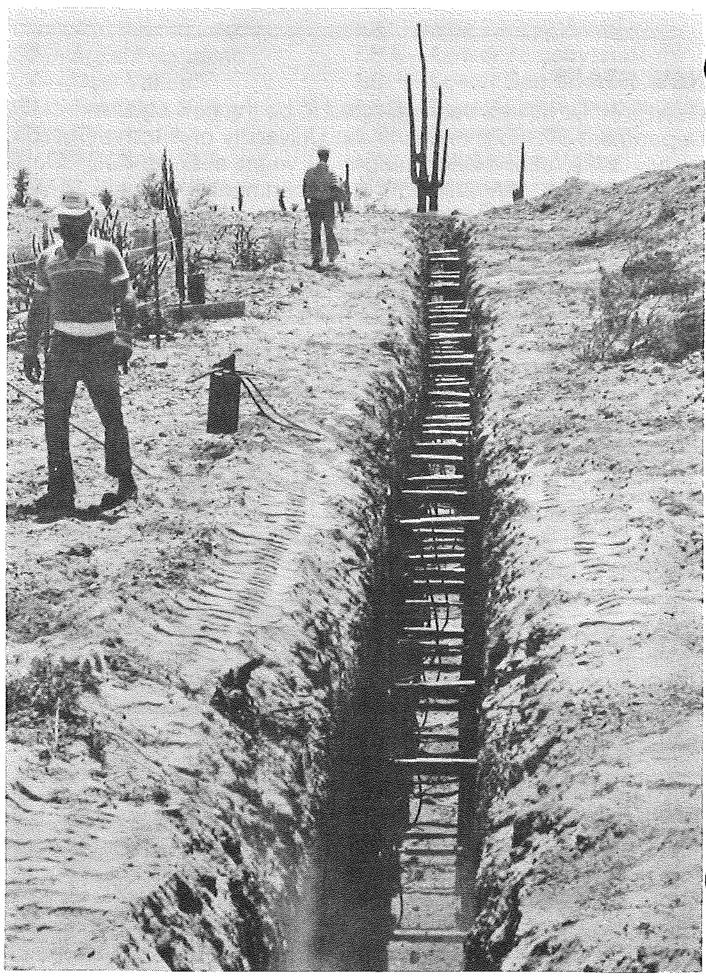


Figure 2. Trench excavated across a scarp, which demonstrated a non-fault origin (June 13, 1982). Photo: Christopher Menges.

RECENT PAPERS ON ARIZONA GEOLOGY

The Geological Society of America Cordilleran Section held its 78th annual meeting April 19-21, 1982 in Anaheim, Calif. Listed below are the authors and titles of some of the presentations on Arizona geology.

Anderson, R. Ernest: Miocene structural history south of Lake Mead, Nevada-Arizona.

Anderson, R. Ernest, Fleck, Robert J., and Bohannon, Robert G.: The Las Vegas valley shear zone, Lake Mead fault system, and extensional tectonics; Lake Mead-Las Vegas valley region, southern Nevada, northwestern Arizona, and southwestern Utah.

Bilodeau, William L.: Basin configuration as a control on the geometry of Laramide deformation in SE Arizona, SW New Mexico, and NE Mexico.

Blakey, Ronald C., and Gubitosa, Richard: Controls of sandbody geometry in the Chinle Formation (Upper Triassic) Colorado Plateau.

Conway, Clay M., Wrucke, Chester T., Ludwig, Kenneth W., and Silver, Leon T.: Structures of the Proterozoic Mazatzal orogeny, Arizona.

Crespi, Jean M., Currier, Debra A., Ditullio, Lee D., Kauffman, Ann Bykerk and Krantz, Robert W.: Superposed faulting in the Huachuca Mountains, southeastern Arizona.

DeWitt, Ed: The geochemistry of Precambrian crust and its effect on younger metallogenesis, Yavapai County, Arizona.

Dickinson, William R.: Space-time evolution of Cretaceous-Tertiary tectonomagmatic provinces in the southwestern United States.

Farmer, G. Lang, and DePaolo, D. J.: A Nd and Sr isotopic study of the hydrothermally altered Laramide porphyry at San Manuel, Arizona.

Frost, Eric G., Martin, Donna L., and Krummenacher, Daniel: Mid-Tertiary detachment faulting in southwestern Arizona and southeastern California and its overprint on the Vincent thrust system.

Grover, Jeffrey A.: Depositional environment and structural relations of the Mineta Formation, Teran basin, Cochise County, Arizona.

Guilbert, John M.: Metallogenic aspects of porphyry copper-molybdenum deposits of Cordilleran North America.

Harding, L. E., Coney, P. J., and Butler, R. F.: Stratigraphy, sedimentary petrology, structure and paleomagnetism of the McCoy Mtns.-Livingston Hills Fm., SE California and SW Arizona.

Haxel, Gordon, Mueller, Karl, Frost, Eric, and Silver, Leon T.: Mid-Tertiary detachment faulting in the northernmost Mohawk Mountains, southwestern Arizona.

Hereford, Richard: Alluvial stratigraphy and discharge of the Little Colorado River, Arizona since 1927.

Huyck, Holly L.: Mineralization of the Lakeshore porphyry copper deposit, Pinal County, Arizona.

John, Barbara E., and Howard, Keith A.: Multiple low-angle Tertiary faults in the Chemehuevi and Mohave Mountains, California and Arizona.

Karlstrom, Thor N. V.: Dating of the type Tsegi and Naha deposits of Holocene age in the American Southwest.

Keith, Stanley B.: Evidence for late Laramide southwest vergent underthrusting in southeast California, southern Arizona, and northeast Sonora.

Keith, Stanley, B.: Laramide structural, magmatic, and metallogenic evolution of southeast California, southern Arizona, and southwest New Mexico.

Larson, Michael K., and Péwé, Troy L.: Investigation and prediction of earth fissures related to ground-water withdrawal, Phoenix, Arizona.

Light, Thomas D., Marsh, Sherman P., and Raines, Gary L.: Mineralization in the Crossman Peak area, Mohave Mountains, Arizona.

Lingrey, S. H., and Davis, G. H.: Kinematic/geometric evolution of the Rincon Mountains metamorphic core complex, southern Arizona.

Lucchitta, Ivo, and Suneson, Neil: Relationship of core complexes, Cenozoic extensional tectonism, and the stable craton near the Colorado Plateau margin in western Arizona.

Mayer, Larry: Constraints on morphologic-age estimation of Quaternary fault scarps based on statistical analyses of scarps in the Basin and Range province, Arizona, and northeastern Sonora, Mexico.

Menges, Christopher M., Pearthree, Philip A., and Calvo, Susanna: Quaternary faulting in southeast Arizona and adjacent Sonora, Mexico.

Morrison, Roger B., and Menges, Christopher M.: Late Pliocene and Quaternary Geology of Arizona.

Moyer, Thomas C., and Sheridan, Michael F.: Bimodal volcanism in the Kaiser Spring area, SE Mohave County, Arizona.

Newell, Roger A.: Geologic setting and geology of lead-zinc-silver deposits of the Tombstone district, Cochise County, Arizona.

Nutt, Constance J.: A model of uranium mineralization in the Dripping Spring Quartzite, Gila County, Arizona.

Otton, J. K.: Involvement of a Mesozoic to early Tertiary thrust terrane in mid-Tertiary crustal extension, west-central Arizona.

Otton, J. K.: Petrogenetic evolution of mid-to late-Tertiary magmatism and associated metal deposits in west-central Arizona.

Ratte, James C., Marvin, Richard F., and Naeser, Charles W.: Tectonic setting and geology of base and precious metal deposits, southwestern Mogollon-Datil volcanic field, New Mexico and Arizona.

Reynolds, Stephen J.: Superimposed Mesozoic and Cenozoic tectonics, west-central Arizona.

Reynolds, Stephen J., Keith, Stanley B., and DeWitt, Ed: Late Cretaceous-early Tertiary peraluminous granitoids of Arizona—California and their related mineral deposits.

Richard, Stephen M.: Structure and stratigraphy of the Little Harquahala Mountains, Yuma County, Arizona.

Shakel, D. W.: Yet another model for metallogenesis of Arizona copper: exclusively Precambrian primary crustal emplacement, storage in selected sedimentary sequences, and concentration by fortuitous Phanerozoic magmatism of various ages and origins.

Strand, Carl L., and Scacifero, Anthony J.: Quaternary fault studies in the Arizona mountain neotectonic province.

Swan, Monte M.: Influence of pre-Cretaceous structure upon Late Cretaceous-Tertiary magmatism in southern Arizona and New Mexico.

Theodore, Ted G., McKee, E. H., Nash, J. Thomas, and Antweiler, John C.: Genesis of Late Cretaceous gold mineralization in the Gold Basin-Lost Basin mining districts, Mohave County, Arizona.

Tosdal, R. M., and Haxel, Gordon: Two belts of Late Cretaceous to early Tertiary crystalline thrust faults in southwest Arizona and southeastern California.

Wilkins, Joe, Jr., and Heidrick, Tom L.: Base and precious metal mineralization related to low-angle tectonic features in the Whipple Mountains, California and Buckskin Mountains, Arizona.

EARTH SCIENCE CENTER II: Gateway to the Past

Figure 1. Beneath a transparency of a painting of the Milky Way and photographs of various nebulae in our galaxy, visitors to the final phase of the Stephen H. Congdon Earth Sciences Center at the Arizona-Sonora Desert Museum trace the 5-billion-year history of the Sonoran Desert. Photo: Arizona-Sonora Desert Museum.

"Over three billion years ago, the earth was in nearly total darkness." So begins the story of this planet's geologic history, in the recently completed gallery at the Arizona-Sonora Desert Museum's Earth Science Center. Scores of exhibits composed of living plants, fossils, photographs, models and artists' works line the walls and ceiling of the elliptical gallery, leading the visitor through geologic time and environmental change.

One can move through the past at an incredible pace in the gallery, viewing occurrences in the earth's development, under a canopy of stars and nebulae. The displays depict the emergence of life through the development of photosynthesis and the formation of an oxygen atmosphere three billion years (b.y.) ago. A sample of the oldest known rock (3 b.y. old metaquartzite from Greenland) is displayed, followed by the earliest known single-cell fossil (1.3 b.y. old) and a single-cell algae fossil from the Grand Canyon, dating 800 million years (m.y.) ago.

Arizona's evolution is outlined: 800–250 m.y. ago, shallow seas covered parts of the state; a coastal plain emerged, with present-day Tucson on the shoreline of an ancient sea, about 250 m.y. ago. Geologic upheavals occurred: Intense volcanic activity formed Arizona's copper deposits 180 m.y. ago at Bisbee; 70–60 m.y. ago the crust was buckled and deformed. One m.y. ago glaciers covered the state's highest peaks and valleys, and the land was surrounded by lush vegetation and water. Twelve thousand years ago, man roamed the area, along with large mammals (horses, bison, ground sloths, camels, mammoths, and sabre tooth cats, extinct by 8,000 B.C.).

A glimpse of the future is provided in an exhibit that wraps up this geologic tour through time. It is projected that climatic changes will occur as the Baja Peninsula breaks away from the continent and moves northward, merging the Gulf of California with the Pacific Ocean.

A unique, circular screen, 15 inches in diameter, occupies the center of the gallery (see Figure 1). This three-dimensional 'orb' depicts 'continental drift' through plate tectonics, as land masses appear to combine, separate, and recombine (e.g., 300 m.y. ago, Arizona was located near present-day Brazil).

The gallery exhibit blends into a hall of minerals and crystals native to Arizona. Precious and semi-precious stones, faceted gems, and micro-minerals sparkle in the dimly lit room. Displays emphasize the importance of copper in the state and nation. For instance, about 150,000 tons of the earth's crust yield enough copper to make a penny; and a person uses 1,750 pounds of copper in a lifetime (represented by a copper cube 17½ inches per side).

The mineral hall leads the visitor through a reconstructed mine tunnel containing four vugs (pockets) of crystals (selenite, wulfenite and mimetite, vanadinite, and malachite) as they actually appear underground. The exhibit ends with a simulated mine dump.

The Earth Science Center II was completed and dedicated in the fall of 1981, following the considerable success of phase I (reconstructed wet and dry caves), finished in 1977. The Potomac Group (Washington, D.C.) designed phase II and General Exhibits (Chicago) created most of the displays, in conjunction with museum staff. Construction and assembly of phase II was performed by museum staff. Implementation of the entire Stephen H. Congdon earth science complex was made possible through bequests and donations from private individuals and industries in Arizona. The total cost was $1.5 million, $700,000 of which went to phase II (see Fieldnotes, v. 10, no. 4, p. 9).

BUREAU PUBLICATIONS

Circular 23, **Geothermal Resources in Arizona: A Bibliography,** by Susanna Calvo; 23 pages; $3.00. Reference reports and maps generated by the Arizona Bureau of Geology and Mineral Technology Geothermal Project and by the Arizona Geothermal Commercialization Team of the Department of Chemical Engineering, University of Arizona, Tucson. Other references include other fields closely related to geothermal (geology, hydrology, geophysics and geochemistry); funding from the U.S. Department of Energy, the U.S. Bureau of Reclamation, and the Arizona Solar Energy Commission.

Geothermal Resources of Arizona, a 1:500,000-scale map, is now available from the Arizona Bureau of Geology and Mineral Technology for $1.00, which includes postage and handling. The study was funded by the Department of Energy; the map was prepared for and printed by the National Oceanic and Atmospheric Administration, and compiled and interpreted by James C. Witcher, Claudia Stone, and W. Richard Hahman, Sr.

Historical Seismicity in Arizona: Final Report, Open-File Report 82-2, by Susan M. DuBois, Marc L. Sbar, and Thaddeus A. Nowak, Jr.; 199 pages with maps; $20.00. Contains epicenter maps (by intensity/magnitude category or by time period), earthquake reports (epicenter, intensity, and date), discussion of tectonic setting of Arizona, seismograph data, and summary of 1887 earthquake (includes attenuation data); funding by Arizona Bureau of Geology and Mineral Technology, U.S. Geological Survey, and U.S. Nuclear Regulatory Commission.

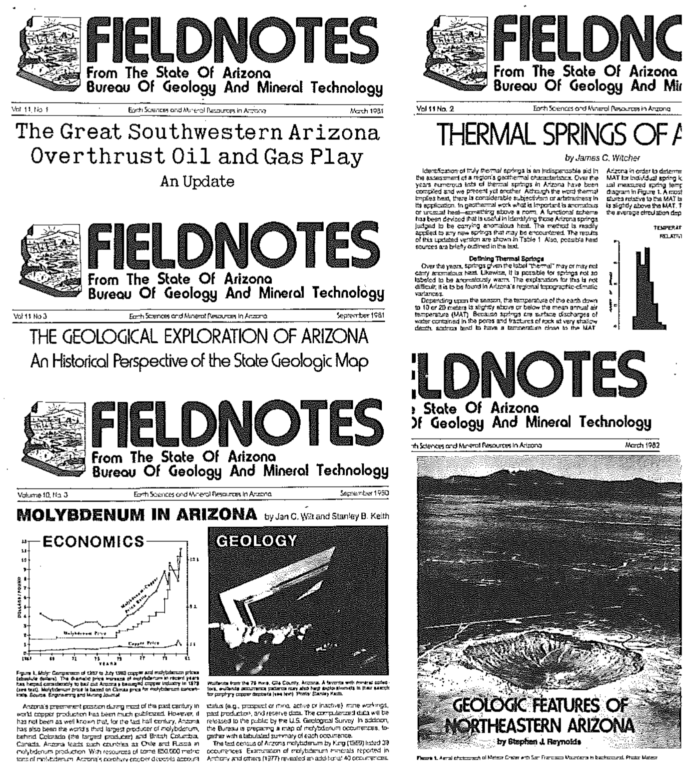
These publications may be obtained from the Arizona Bureau of Geology and Mineral Technology Publications Desk or by mail (with 20% handling charge).

NEW PUBLICATION

Anderson-Hamilton Volume: **Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada,** edited by Eric Frost and Donna Martin; 616 pages with nearly 200 photos. Compilation of 77 authors' studies, from the U.S. Geological Survey, the U.S. Bureau of Mines, and many universities and industry; obtained from Cordilleran Publishers, 6203 Lake Alturas Ave., San Diego, California, 92119, for $25.00 plus $2.50 postage and handling.

REQUEST FOR GEOLOGIC DATA

The Arizona Bureau of Geology and Mineral Technology is presently compiling geologic mapping and radiometric ages for the areas covered by the Tucson, Phoenix, and Nogales 1 x 2° Quadrangles (scale 1:250,000). Anyone possessing unpublished geologic mapping or radiometric ages in these areas is asked to contact Stephen Reynolds, Arizona Bureau of Geology and Mineral Technology at 845 N. Park Ave., Tucson, Arizona 85719 (602/626-2733).



Fieldnotes is a 12-page newsletter published quarterly by the Arizona Bureau of Geology and Mineral Technology. A subscription is free of charge and may be obtained by contacting the Arizona Bureau at 845 N. Park Ave., Tucson, Arizona 85719 (602/626-2733). Address changes should accompany the previous address label, if possible.

ARIZONA GEOLOGICAL SOCIETY FIELD TRIP

The Arizona Geological Society Spring Field Trip, led by Dr. Larry K. Lepley, was held May 1, 1982 in Safford, Arizona. The purpose of the trip was to compare images derived from an aerial multispectral scanner designed to simulate the Thematic Mapper to be included on the future Landsat D satellite.

The area examined on this field trip is one of three porphyry copper deposits evaluated, under contract with the National Aeronautics and Space Administration (NASA), as part of a joint NASA-Geosat test case study by the Jet Propulsion Laboratory (JPL), California Institute of Technology, and geologists from U.S. mineral and petroleum exploration companies, under the auspices of the Geosat Committee, Inc. Project goals were: 1) to evaluate remote sensing techniques for detection of alteration, structures, and stratigraphy associated with porphyry copper deposits, and 2) to make recommendations for future sensor systems more applicable to exploration problems.

Three areas in Arizona—Safford, Helvetia, and Silver Bell—were selected for evaluation because they include a variety of copper occurrences in a semi-arid climate with different host rocks, levels of erosion, and stages of development. Research on the project was done by Michael Abrams, JPL, California Institute of Technology, Pasadena; David Brown, Texasgulf, Tucson; L. K. Lepley, Consultant, Tucson; and Ray Sadowski, AMAX, Tucson.

A limited number of the field trip guidebook, "Comparison of NASA Thematic Mapper Images of the Safford District with exposed alteration haloes at the Phelps Dodge Dos Pobres and Kennecott Lone Star deposits" are available for purchase from the Arizona Geological Society, P.O. Box 40952, Tucson, Arizona 85717 ($35.00); the guidebook may also be reviewed at the Arizona Bureau of Geology and Mineral Technology Library.

BUREAU OUTREACH

In February 1982 Dr. H. Wesley Peirce talked to students, faculty, and guests of the Northern Arizona University Geology Department. He discussed the history and origin of Oak Creek Canyon, an outgrowth of his work along the Mogollon Rim, noting that the geologic history was considerably more complex than previously thought. In particular, he pointed out the necessity of understanding the geologic history of the Oak Creek fault zone, if canyon genesis is to be properly comprehended.

In April, Dr. Peirce attended the 18th Forum on Geology of Industrial Minerals, held on the campus of Indiana University at Bloomington. The meeting was sponsored by the Indiana Geological Survey and the Department of Geology. Field trips included visits to: 1) one of the nation's largest gypsum mining (underground) and product processing facilities; 2) the center of Indiana's famous dimension-limestone quarrying and milling industry; and 3) both surface and underground mining operations that produce vital aggregate for the Indianapolis region. Such meetings are of interest to the Bureau because of its continuing efforts to remain informed about how rocks and minerals of all kinds are exploited, processed, and utilized. As the population of the Southwest continues to grow, and technology evolves, demands for an ever enlarging array of rock-based natural resources are increasing. The Arizona Bureau of Geology and Mineral Technology will host the 21st Forum in 1985.

In May, Peirce was one of three scientists taking part in a program arranged for an American College of Physician's Arizona Section Meeting at Sedona. Using slides, he illustrated what Arizona is, geologically, and how its inherited geologic characteristics control where we live and what we do [no rocks—no doctors!].

In June 1982 Dr. Peirce was a participant in a Natural Resources Workshop for Arizona Youth, sponsored by the Society for Range Management. Forty-five young men and women gathered at a camp facility in the Prescott National Forest for a week of natural resources-related instruction and field activity. Peirce emphasized the fundamental ecological role of rocks, minerals, and soils.

Dr. Larry Fellows attended the 74th Annual Meeting of the Association of American State Geologists in Hershey, Pennsylvania, in early June 1982. The meeting was hosted by the Pennsylvania Bureau of Topographic and Geologic Survey. Each year state geologists, selected state geological survey staff, and invited guests (including federal agency directors and staff) meet to inform each other about current or projected activities, to discuss problems and projects of mutual interest, and to identify ways of cooperating. Forty states were represented.

This year attention was focused on the effects of state and federal budget reductions on providing geologic data and service pertaining to the management of land, mineral, water, and energy resources. Another topic of considerable interest was the establishment by Secretary of Interior James Watt, of the Minerals Management Service, which is comprised primarily of what formerly was the Conservation Division of the U.S. Geological Survey. Representatives of western states were particularly interested in learning about the Geology, Energy, and Minerals (GEM) assessment program, recently initiated by the U.S. Bureau of Land Management.

Dr. Stephen J. Reynolds, geologist with the Arizona Bureau of Geology and Mineral Technology, has lectured at various universities, state agencies, and professional conferences. Early in the year, he delivered formal presentations at the University of Arizona and Northern Arizona University. In both cases, he discussed the major thrust faults that he and other workers have recently mapped in western Arizona.

Dr. Reynolds was also invited to present talks to other universities in the western United States. For these occasions, Steve's travel expenses were paid by out-of-state universities. At San Diego State Univ.last March, Reynolds presented the results of his geologic research in west-central Arizona, an area of complicated faulting and folding. He also spent much time in the classroom with professor Eric Frost and his students, discussing their geologic studies along the lower Colorado River. Reynolds later traveled to the University of Texas at El Paso to talk about whether the overthrust belt, an area favorable for petroleum (see page 5), actually extends through southern Arizona, as some geologists have proposed. Reynolds concluded that an overthrust belt, like that known in Utah and Nevada, does not cross southern Arizona. He discussed these conclusions with UTEP professors who have geophysical and stratigraphic data that bear on the issue. In May, Reynolds presented a talk to the University of California at Davis on his research in Phoenix South Mountain Park, and conferred with professors and students at Davis about their planned microsopic studies of selected rocks from the South Mountains.

Dr. Reynolds also delivered two scientific talks at the annual meeting of the Geological Society of America Cordilleran Section, in Anaheim, California (see page 9). One talk concerned a certain type of granite in Arizona and its potential for mineral deposits. At the other session, Reynolds described the age of faulting and mountain building in west-central Arizona. He also participated in pre-and post-meeting field trips in western Arizona and adjacent southeastern California. These field trips were well attended by geologists from various companies, universities, and federal agencies.

Reynolds has also given nontechnical talks on the geology of Arizona to various state agencies of Arizona (Departments of Water Resources, Transportation, Land, Mineral Resources, and Health Services; State Library, and Office of Economic Planning and Development). At these talks, Dr. Reynolds utilized color slides and maps to illustrate how the major geologic features of Arizona influence our daily lives. ⚒

Fieldnotes

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