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

Volume 10, No. 4 Earth Sciences and Mineral Resources in Arizona December 1980

URANIUM

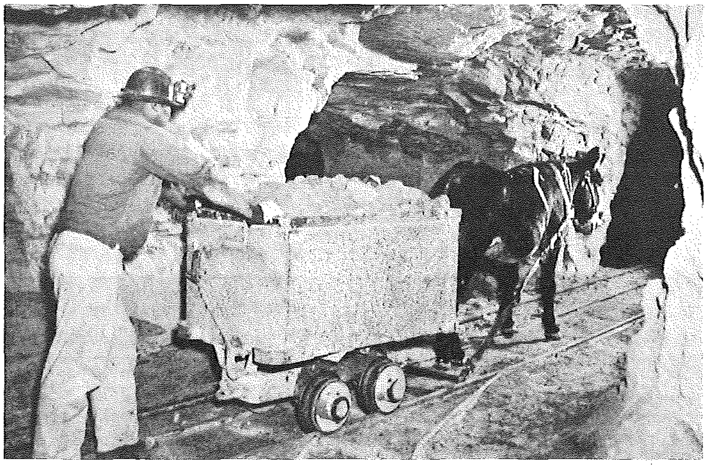
IN ARIZONA

by Robert B. Scarborough

The boom in the uranium industry during the 1950s and 1960s affected Arizona, as well as many other western states. According to Department of Energy production records, 18 million pounds of uranium concentrate have been produced from 328 mines in seven major areas in Arizona, mostly between 1948 and 1969. These seven areas, and the geologic environments from which the uranium has been extracted, may be grouped in order of decreasing production, as follows:

1. Monument Valley—Shinarump Conglomerate
2. Orphan lode—breccia pipe
3. Lukachukai Mountains—Morrison Formation
4. Cameron area—Chinle Formation
5. Carrizo Mountains—Morrison Formation
6. Sierra Ancha Mountains—Dripping Spring Quartzite
7. Black Mountain area—Toreva Formation

A number of other geologic environments in Arizona that are known to contain many anomalous concentrations of uranium are listed below and categorized in Figure 1. Asterisks precede those environments with minor uranium production.



Uranium-vanadium ore being removed from a mine in the Lukachukai Mountains of northeast Arizona during the early 1950s. This mine, operated by Kerr-McGee Co., was developed in the Jurassic-age Salt Wash Member of the Morrison Formation. Sedimentary rocks of this age still are the largest producers of uranium ores in the U.S. Photo from U.S. Bureau of Mines.

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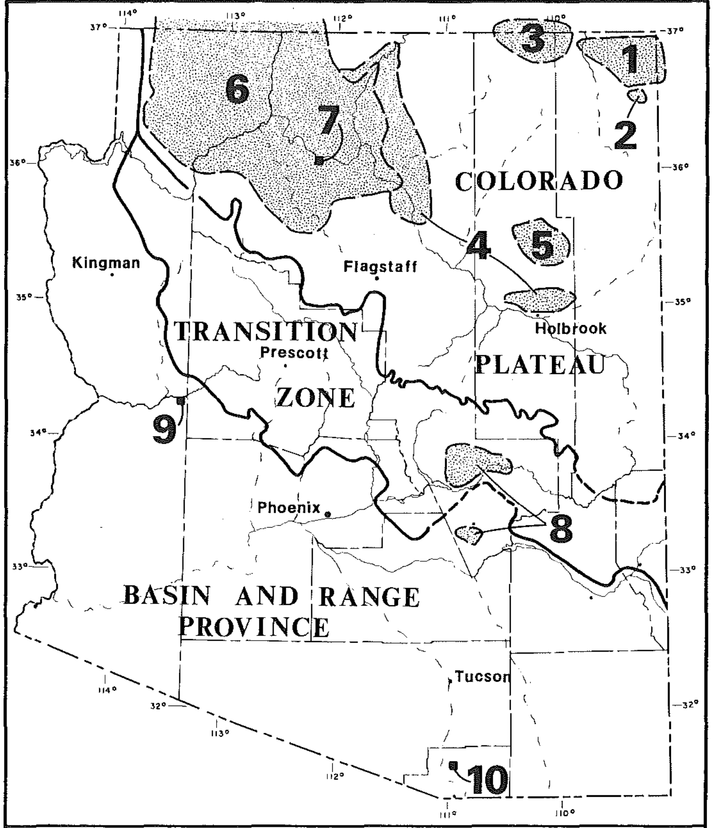


Morrison Formation, Salt Wash Member
1. Carrizo Mountains
2. Lukachukai Mountains

Chinle Formation
3. Shinarump Member, Monument Valley
4. Cameron area, lower sands

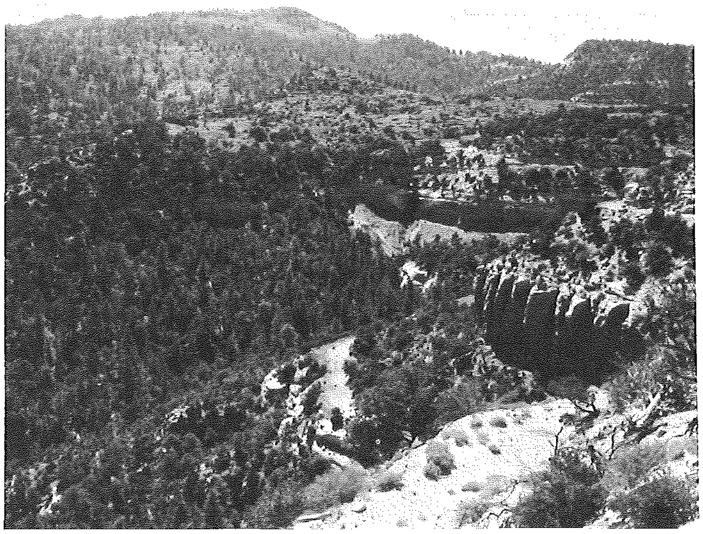
Other districts
5. Hopi Buttes volcanic field
6. Plateau breccia pipes
7. Orphan lode
8. Dripping Spring Quartzite
9. Anderson mine
10. Duranium mine

Figure 1. Areas of Uranium Production and Occurrences

COLORADO PLATEAU PORTION
Moenkopi Formation (basal part), Triassic age
* Kaibab Limestone, Permian age
Navajo Sandstone, Jurassic age
Dakota Formation, Cretaceous age
Kayenta Formation, Jurassic-Triassic age
Naco-Supai Formation conglomerates, late Paleozoic age
* Sediments in Hopi Butte volcanic field, Cenozoic age

BASIN AND RANGE PORTION
* Cretaceous sandstones, southeast part of the state
* Oligocene-Miocene-Pliocene sediments
Oligocene-Miocene volcanic rocks
* Jurassic-Cretaceous volcanics
* Laramide porphyry copper deposits and vein systems
* Vein-pegmatite-fissure occurrences, often involving Precambrian crystalline terrain

Clearly, uranium is found in many different areas and geologic environments. This may be a reflection of the relative chemical mobility of uranium when compared with other heavy metals. Once leached from a source area, uranium migrates easily in aqueous solution until fixed or precipitated by sulfur or organic molecules. This geochemical tendency in nature produces two classes of uranium deposits, either magmatic-hydrothermal or secondary. The type of uranium deposit is thus determined by the uranium's association with magmatic or hydrothermal (hot water) activity, or whether it has been transported for some distance by groundwater and deposited in favorable environments, most often in sediments.



View looking southeast in the uranium mining country of the Lukachukai Mountains of Apache County. Rim strips and access roads are built mostly on cliffs of Salt Wash Member of Morrison Formation. Last mining in this area was in 1968. Photo by R. Scarborough.

Uranium in porphyry copper deposits, or in pegmatites, are examples of the first type of deposit, whereas uranium in the Morrison and Chinle Formations of the Colorado Plateau are examples of the second type. Certain other deposits, such as in Plateau breccia pipes, tend to have characteristics of both types of deposits.

ARIZONA URANIUM OVERVIEW

Worldwide, much uranium is produced from crystalline rocks, such as alkali-rich granites; but in the United States, virtually all uranium production is from sedimentary rocks, mostly in New Mexico, Colorado, Utah and Wyoming. Most U.S. production is from Mesozoic-age sediments (240–65 million years old), except in Wyoming where they are Cenozoic (65 million years to present).

The vast majority of Arizona uranium production has been from the Colorado Plateau portion of the state (Figure 1 and Table 1), from Mesozoic sediments which are similar in geologic setting to the larger deposits in adjacent Utah, Colorado and New Mexico. The main geologic sources for Arizona production are the Triassic (225–190 m.y.) basal Chinle Formation including the Shinarump Conglomerate Member in Monument Valley, and the Jurassic (190–140 m.y.) Salt Wash Member of the Morrison Formation in the Carrizo and Lukachukai Mountains. The other principal source in Arizona has been the Orphan lode breccia pipe in Grand Canyon National Park. Together, these areas account for about 99% of all production of Arizona uranium. The Cretaceous Toreva Formation of Black Mesa and the Precambrian Dripping Spring Quartzite of the Sierra Ancha and vicinity account for most of the remaining 1%, while scattered, small shipments from the Basin and Range country make up the remainder.

MAJOR PAST PRODUCERS IN ARIZONA

Morrison Formation

Historically, the Salt Wash Member of the Morrison Formation in the eastern Carrizo Mountains was the earliest Arizona source of radioactive minerals. Around 1920, small amounts of uranium ore were shipped to Colorado for extraction of radium. Later, six mines in the western Carrizo Mountains shipped some Salt Wash vanadium ore during World War II (1942–1944). Finally, in 1948, these and other Carrizo mines began supplying uranium for national defense purposes under the auspices of the newly created U.S. Atomic Energy Commission. This production had been fostered by preliminary mapping and feasibility studies by Union Mines Development Corporation (UMDC) personnel, organized by the Army Corp of Engineers for the Manhattan Project during 1943–1946. Shortly thereafter, in 1950–1951, uranium was discovered in the nearby Lukachukai Mountains and development quickly followed. Around 1950, the U.S. Geological Survey started regional geologic studies of the Colorado Plateau based on its uranium potential, which, among other things, allowed the discovery of uranium minerals at the Orphan Mine in the Grand Canyon in 1951. See Chenoweth (1980) for further details.

Between 1948 and 1966, about 50 mines in the Lukachukai Mountains and another 93 in the Carrizos produced approximately 3.9 million pounds of uranium (U_3O_8) from ores containing about 0.23% U_3O_8 and about 1.2% vanadium (V_2O_5). Most of this ore was

TABLE 1

ARIZONA URANIUM PRODUCTION, 1948–1970

	Tons of Ore	Pounds of U_3O_8	Average U_3O_8 Grade	Pounds of V_2O_5	Average V_2O_5 Grade	Years of Production
Black Mountain District	16,900	57,600	0.17%	26,000	0.08%	1951–1967
Plateau breccia pipes	511,000	4,374,600	0.43%	—	—	1950–1972
Cameron area[1]	295,100	1,240,000	0.21%	211,900	0.036%	1954–1963 1977–present[2]
Carrizo Mountains	90,300	364,900	0.20%	3,166,200	1.75%	1948–1966
Lukachukai Mountains	724,800	3,483,300	0.24%	14,730,000	1.02%	1950–1968
Monument Valley	1,322,000	8,670,000	0.33%	24,361,400	0.92%	1948–1969
Sierra Ancha District	25,500	115,200	0.23%	—	—	1953–1960 1977–present[3]
Southern Arizona; all sources in Cochise, Graham, Pima, Santa Cruz, Yavapai and Yuma Counties (11 producers)	11,600	36,700	—	10,300	—	1954–1959 1977–present[4]
TOTALS	2,997,200	18,342,300	0.31%	42,505,800	—	

[1] Includes Marble Canyon-Vermillion Cliffs area and one producer in the Kaibab Ls.

[2] One known producer in Holbrook area

[3] Two known producers; one in Pinal Mts., one in Sierra Ancha

[4] One known producer in Rincon Mts. area

obtained through underground room-and-pillar techniques with adits or surface declines driven from mesa rims developed on cliffs of the Salt Wash Member of the Morrison Formation.

The Salt Wash Member of the Morrison Formation is interpreted as continental fluvial-floodplain deposits (Chenoweth and Malan, 1973); the uranium-vanadium ores are stratigraphically confined to certain mudstone and sandstone layers which contain abundant fossil woody-plant trash and carbonized log fragments. Ore grade is closely associated with organic content, which, in turn may be related to the position of point bar deposits with respect to paleomeander bends in the stream courses.

Most workers interpret the ore deposition as quickly following sediment deposition, before later diagenesis solidified the mudstones. In the Carrizo Mountains at the Zona Mine, Chenoweth and Malan (1973) interpreted the ore deposition to have taken place before the Salt Wash sediments were intruded and baked by the Laramide-age Carrizo Mountain laccoliths. Hence the ore deposition is pre-Laramide (~ 70 m.y.) in age.

An unexplained attribute of the Salt Wash ores is a ratio of vanadium to uranium of approximately 4:1 up to 8:1. This ratio is a high for Arizona uranium deposits and accounts for 17.9 million pounds of V_2O_5 production from mines in the Salt Wash Member alone. The uranium and vanadium apparently migrated together under appropriate geochemical conditions, presumably from the source area of the Salt Wash sediments, somewhere to the west of what is today Lee's Ferry on the Colorado River (Craig and others, 1955).

Chinle Formation

The basal part of the Triassic Chinle Formation in the Cameron area and in the Monument Valley region of Arizona and Utah had sustained production of uranium between 1948 and 1969. In the Cameron area, the lower part of the Chinle Formation (termed the sandstone and siltstone member by Repenning and others, 1969, p. 5) and various horizons in the Petrified Forest Member contain ore zones that consist of interbedded sands and mudstones with abundant silicified logs. These strata are exposed along both sides of the Little Colorado River for 40 miles. A total of 102 mines, most of which were open pits averaging between 20 and 60 feet deep, produced 1.24 million pounds of U_3O_8 and 212,000 pounds of V_2O_5 between 1954 and 1963 (see Bollin and Kerr, 1958). These mined areas represent only the most accessible ore bodies. Certainly, some potential for slightly deeper ore bodies remains in the area, as suggested by some recent drilling results. In the eastern part of the Cameron area, minor production is recorded from the basal Kayenta Formation.

Monument Valley has been the single most productive area for uranium in Arizona. In this region, well-defined channels of the basal Chinle conglomerate (the Shinarump) were cut into the underlying Triassic Moenkopi Formation and were subsequently mineralized locally. The channel fill consists of pebbley conglomerates with sandstone and mudstone lenses and locally abundant carbonized and silicified logs. Total Monument Valley production from 34 mines between 1948 and 1969 amounts to 8.7 million pounds of U_3O_8 and 24.4 million pounds of V_2O_5. Arizona's largest single mine group is the Monument No. 2 mine, operated by the Vanadium Corporation of America. This Monument mine is in an erosional remnant of a low scour in a single Shinarump channel, with both upstream and downstream portions removed by later erosion. The preserved channel remnant is cut through the Moenkopi Formation into the underlying De Chelly Sandstone, and is about 700 feet wide and up to 60 feet deep. Monument No. 2 production alone accounts for 5.2 million pounds of U_3O_8 and 21.8 million pounds of V_2O_5 from 1952 to 1967. Earlier underground workings were eventually replaced by an open pit which followed the course of the Shinarump channel. Production was enhanced from 1955 to 1964 by a mechanical upgrader situated near the mine that separated higher grade clay-silt ore averaging 0.24% U_3O_8 and 2.6% V_2O_5 from more sandy materials (0.02% U_3O_8 and 0.18% V_2O_5) which were discarded. During 1964–1967, heap leaching of the sand residue and some low grade ore resulted in additional production. Ore minerals at Monument No. 2 are tyuyamunite, carnotite, becquerelite, hervettite and uraninite; they impregnate sandstone lenses, fill fractures, and replace clay and fossil plant fragments. Most workers hypothesize ore deposition in Shinarump channels to have occurred through the trapping of uranium-vanadium minerals by organic debris in the channels from groundwater solutions which were moving through the permeable channelways in the post-Shinarump time. However, Finnell (1957) suggests a Laramide age of low-temperature hydrothermal ore deposition.

Mining at the Charlie Huskon No. 3 open pit in the Cameron area, April 1966. Uranium here is in sands and shales of the Triassic-age Chinle Formation. Petrified wood in the sediments is especially uranium rich. Photo by W. Chenoweth, Dept. of Energy.

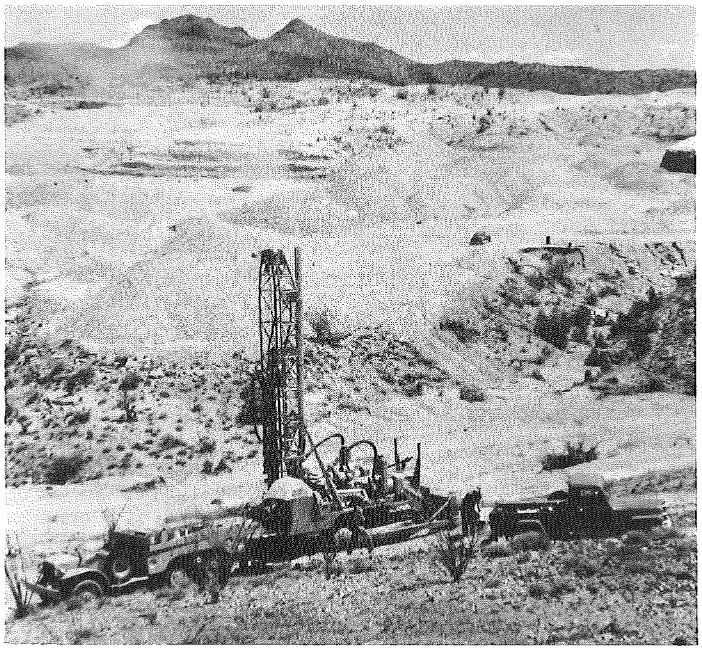
Breccia Pipe Sources

Breccia pipes are found in large areas of the Colorado Plateau country. More than 100 have been postulated by DOE subcontract studies to exist in the region surrounding the Grand Canyon. The pipes take the form of vertically elongate, cylindrical masses filled with heterogeneous assemblages of sedimentary rock fragments that have been displaced downward, presumably by collapse into a solution cavity formed in Mississipian-age Redwall Limestone. Radial and concentric faults and fractures mark the lateral pipe boundaries. Where explored, the pipes never contain sedimentary material that can be proven to have moved upward, nor do they contain any volcanic debris. Many, but by no means all, of the Arizona Plateau pipes contain varying degrees of copper and/or uranium mineralization. Past uranium production in Arizona is recorded from five pipes. The first four (Chapel, Hack Canyon, Ridenour and Riverview) supplied a cumulative total of 1852 tons of uraninite-type ore that contained about 0.5% U_3O_8 between 1950 and 1964. The fifth, the Orphan Lode, is the second largest individual Arizona uranium mine. It is credited with 509,000 tons of ore that contained 0.43% U_3O_8, and with considerable values of copper and silver. Vanadium content was quite low.

The Orphan ores are mostly primary uraninite-pyrite-chalcocite-tennantite, with some secondary ores found near the present surface of the mine, 1,000 feet below the top of the Grand Canyon. The ores have been subdivided into basically two types. A central "B" orebody occupies a "pipe within a pipe" structure, where the ore has impregnated the highly brecciated pipe-fill derived largely from the Coconino Sandstone. The annular ring orebody is found mostly outside the pipe perimeter, 200–400 feet below the surface. Outside of the pipe perimeter, rich ore selectively replaced certain mudstone layers in the Supai Formation. For details of Orphan geology, see Gornitz and Kerr (1970) and Kofford (1969).

Ore mined in 1956 to 1959 was hoisted to the canyon rim by an aerial bucket tramway with a 1,000 ton-per-month capacity. From

Adits in the Little Joe-Workman mine areas of the Sierra Anchas of Gila County. Uranium is contained in the late Precambrian Dripping Spring Quartzite. This area is continuing as an exploration target in the 1980s. Photo by R. Scarborough.



Mining and drilling in 1958 at the Anderson mine of Yavapai County. Renewed drilling in the 1970s outlined a large low-grade uranium orebody nearby which now awaits favorable economic conditions for further development. Photo by W. Chenoweth, Dept. of Energy.

1959 on, ore was hoisted through a crosscut and 1,600 foot shaft directly to the canyon rim. Most ore was trucked to the Rare Metals Mill in Tuba City.

More than 60 exotic minerals have been identified at the Orphan mine. Detailed analyses indicate primary ore deposition at temperatures of 60° to 110° C, with uranium-lead age dates suggesting a Jurassic age of ore deposition. Interestingly, this very nearly coincides with the age of the Morrison Formation sedimentation in the Four Corners region to the east.

Other Arizona Production

Between 10,000 and 20,000 tons of uranium ore have been shipped from each of three other sources in Arizona: The Cretaceous Toreva Formation on the eastern extent of Black Mesa; the Precambrian Dripping Spring Quartzite of the Sierra Ancha of Gila County; and scattered shipments from 11 different sources in the Basin and Range portion of the state. The Toreva Formation and Dripping Spring Quartzite ores are both interpreted as stratabound deposits (Chenoweth and Malan, 1973; Williams, 1957). The two largest southern Basin and Range sources (both in the 1950s) have been the Anderson mine of Yavapai County (consisting of Miocene carbonaceous and siliceous sediments) and the Duranium mine of Santa Cruz County (a shear zone in Cretaceous quartzites).

RECENT TRENDS IN URANIUM INDUSTRY

The 1970s has been a decade of increased exploration and mining of uranium on a national scale. During this ten-year period, average production figures (DOE open file report 100(80)) for New Mexico were 6,200 tons of U_3O_8 concentrate *per year,* 4,400 tons *per year* for Wyoming, and 4,300 tons *per year* for all other states combined (Colorado, Utah, Washington and Texas). Viewed in comparison with these figures, the total *cumulative* Arizona uranium output to date is 9,164 tons of U_3O_8, or 2.82% of the U.S. cumulative total production for 324,900 tons of U_3O_8 as of January 1, 1980. Nationally, 1979 drilling footage for uranium was distributed geographically as follows: 35% in Wyoming basins, 33% on the Colorado Plateau, 20% in west Gulf Coast plains, about 2.5% in the Basin and Range Province, and about 10% in all other areas.

RECENT ACTIVITY IN ARIZONA

Although Arizona has only produced moderate amounts of uranium in the past, considerable exploration efforts have been expended in the state during the last decade, particularly in reference to breccia pipe and Cenozoic sedimentary targets. Recent trends of exploration drilling in Arizona are illustrated in Table 2. Land held for exploration and development by companies and individuals in Arizona was at an all-time high at about 1.7 million acres, as of January 1, 1980, up 30% over the January 1979 holdings. Drilling in the first half of 1980 was down about 50% from the same time in 1979, probably related at least in part to nuclear reactor cancellations following the Three Mile Island incident. The drilling peak in 1976 was centered around renewed interest in the Miocene sediments of the Date Creek basin of Yavapai and Yuma Counties. During this surge, Minerals Exploration and Urangeshelshaft drilled out low-grade ore reserves in excess of 30 million pounds of U_3O_8 in the shallow subsurface near the Old Anderson mine *(Fieldnotes,* v. 9, n. 3, p. 15). Announcements in 1977 of new mining and milling plans were temporarily canceled in mid-1980 because of financial considerations. However, considerable interest remains in the Date Creek basin area and many other Cenozoic sedimentary deposits (see Otton, 1977; Scarborough and Wilt, 1979).

TABLE 2

EXPLORATION DRILLING FOR URANIUM IN ARIZONA, 1970–1980

Calendar Year	Number of Holes	Footage
1970	14	3,500
1971	24	2,200
1972	37	6,000
1973	50	8,700
1974	127	52,000
1975	1,165	176,200
1976	1,465	544,700
1977	1,035	500,400
1978	1,372	688,300
1979	663	378,400
1980*	98	64,300

*First six (6) months only. Source: W. Chenoweth, DOE, Grand Junction

Exploration drilling in Cenozoic sediments has also been performed in several other areas. Portions of other southern Arizona valleys have been drilled to test for Date Creek basin analogs, generally with discouraging results. Some low-grade resources have been located in Miocene-age bedded dolomites in the New River area of Maricopa County.

Considerable exploration is underway on the Colorado Plateau for buried breccia pipes similar to the Orphan lode. Although many pipes exist in the Grand Canyon-Arizona strip country, it is likely that many are buried under surficial cover rocks, and require advanced geophysical techniques for target discovery. Energy Fuels Nuclear, Inc. of Denver has recently announced the discovery of a previously unknown ore-bearing pipe along Hack Canyon, north of the Grand Canyon, which could yield 500,000 tons of ore, and perhaps half the U_3O_8 content of the Orphan lode.

Drilling has continued in the Sierra Ancha region to further test the Dripping Spring Quartzite. New potential ore deposits are being explored in the Workman Creek area in the central part of the district, and around the old Red Bluff mine in the southern part of the district. The old Lucky Boy mine in the southern Pinal Mountains produced some uranium in the 1950s from the Dripping Spring Quartzite. The mine has been reopened and several shipments of brine concentrate have been made since 1977.

Shipments of yellow cake (uranium oxide) were initiated in April 1980 by Anamax from their Twin Buttes open pit copper mine in the Pima Mining district of the Sierrita Mountains. They anticipate shipping approximately 120,000 pounds of concentrate, extracted from a secondary leach circuit, in the first year. This is an amount equivalent to the total production thus far obtained from the entire Sierra Ancha district. Phelps Dodge Corporation anticipates some leach solution recovery from their copper mines at Bisbee and Morenci.

Some drilling has been done to test for targets in Precambrian granites in the Redington Pass area of the Rincon Mountains, in the northern Whetstone Mountains, and in Jurassic granite in the southern Santa Rita Mountains. These occurrences are usually associated with shear zones or hydrothermally altered areas.

The Department of Energy, through its subcontractors, has expended considerable exploration time in Arizona during the past decade. DOE's National Uranium Resources Evaluation program (NURE) is administered by Bendix Field Engineering Corporation, which is now preparing folios of investigation for parts of Arizona and New Mexico, including the Kingman, Prescott, Marble Canyon, Williams, Shiprock, Gallup, Flagstaff, St. Johns, Mesa, and Grand Canyon 1° x 2° (NTMS) quadrangles. In addition, NURE fieldwork on the Nogales, Douglas, Clifton and Silver City quads is nearing completion as of December 1980. The NURE folios include the evaluation of all major geologic environments in the quadrangles for uranium potential, and provide many detailed petrographic, chemical and gamma ray spectrometric analyses of major rock units of the quadrangles.

A variety of other projects in Arizona has been funded by DOE: Deep drilling in the Date Creek basin region; detailed hydrogeochemical sampling around Artillery Peak, Mohave County and the Cerbat Mountains; and detailed studies of certain geologic environments, such as older Precambrian conglomerates and metamorphic core complexes. The hydrogeochemical work (HSSR program of Bendix) will appear in summary form within the NURE folios. The detailed studies ("World Class" program of Bendix) will be issued as individual open-file reports upon completion. Questions regarding the availability of any of these reports may be addressed to the Bendix Library, P.O. Box 1569, Grand Junction, CO 81501.

This report is a summary of a Department of Energy-funded compilation of uranium occurrences and producers in Arizona; it was prepared by Robert B. Scarborough and Peter L. Kresan.

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LOCAL EVENTS

Tucson Gem and Mineral Show: **Tucson Gem and Mineral Society,** Tucson, AZ, February 13–15, 1981.

Geoscience Daze—9th Annual Student Presentations: **Department of Geosciences,** University of Arizona, Tucson, AZ (Contact: Mike Williams), March 4–6, 1981.

Symposium on tectonics and ore deposits: **Arizona Geological Society and University of Arizona,** Tucson, AZ, March 19–20, 1981.

NATIONAL/REGIONAL EVENTS

Geological Society of America—Annual Meetings:
  Cordilleran Section, Hermosillo, MX, March 23–29, 1981.
  Rocky Mountain Section, Rapid City, SD, April 16–17, 1981.

Cerro Prieto Geothermal Field of Baja California, Mexico—Symposium: **Univ. of California, Earth Sciences Div.,** Berkeley, CA, March 24–27, 1981.

American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists:
  Rocky Mountain Section, Albuquerque, NM, April 12–15, 1981.
  Annual Meeting, San Francisco, CA, May 31–June 3, 1981.

Advances in Geotechnical Earthquake Engineering and Soil Dynamics—Meeting: **University of Missouri,** Rolla, MO, April 26–May 2, 1981.

Geology of Industrial Minerals—Forum: **New Mexico Bureau of Mines,** Albuquerque, NM, May 13–15, 1981.

GRADUATE RESEARCH ASSISTANT

The recipient of the Research Assistantship awarded by the Bureau of Geology and Mineral Technology for 1980–81 is Steven Lingrey, a PhD candidate in the Geosciences Department at the University of Arizona. Mr. Lingrey will be mapping and interpreting the structural geology of the northeastern Rincon Mountains in Pima and Cochise Counties, Arizona.

Mr. Lingrey received a MS degree in geology at the University of Southern California and has been a student at the University of Arizona since August 1977. His major advisor is Dr. George Davis.

DESERT RUNOFF : Hazards in Arizona

by Susan M. DuBois and Brian R. Parks

Each year Arizonans experience extensive losses due to desert runoff. Since 1862 runoff processes have resulted in at least 194 deaths (recorded) and more than $475 million in property and agricultural losses. Fifty-eight percent of this estimated cumulative monetary loss has occurred during the past ten years, 43 percent since 1975.

The curves in Figure 1 show a clear trend toward increasing losses with succeeding high-flow events throughout the historical runoff record, especially in recent years. Moreoever, surges in losses appear to coincide with surges in urban population growth. Possible factors relating these two curves will be discussed later. Figure 2 illustrates that runoff-related damage has occurred frequently in all populated regions of the state.

Flooding is the most common term applied in discussions of hydrologic risk. Often, the word is used synonomously with *runoff* or *erosion*. However, technically defined, flooding describes a condition of overbank flow, a spreading of water onto a floodplain*, away from a runoff channel. In Arizona, as elsewhere, much so-called flood damage actually takes place during non-flood stage runoff periods, when flowing water is confined by well-defined but frequently shifting banks. Several examples follow:

1) Flash "flooding" occurs when water suddenly flows in a wash that was previously dry (Figure 3A). Potential victims include hikers, campers or motorists who either do not heed threatening weather signals or who choose to cross a rushing and powerful stream. Unfortunately, many people fail to view *dry washes* as active water conduits.

2) A continuous natural process of a flowing stream is bankcutting, or lateral erosion. This activity is concentrated along the outside bank of a meander, where water is moving most rapidly around the bend. Undercutting of soft bank material leads to cave-ins and channel migration (Figures 3B and 3C). During high

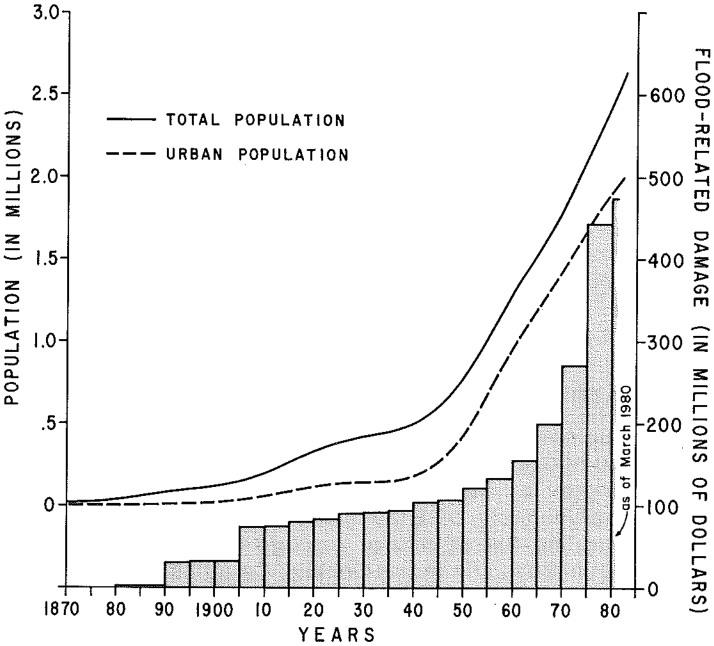


Figure 1A. Cumulative damage from high runoff over five-year intervals. Note that increased losses coincide with increased urban population.

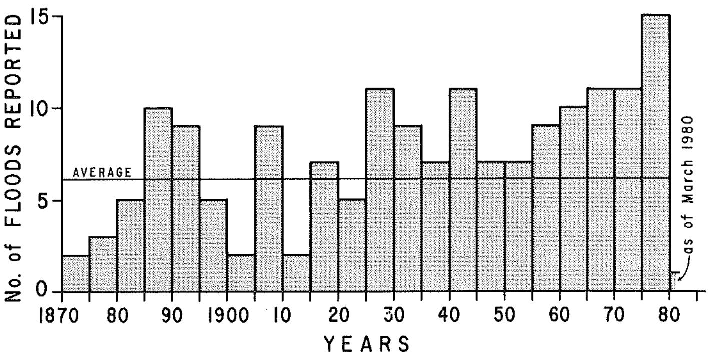
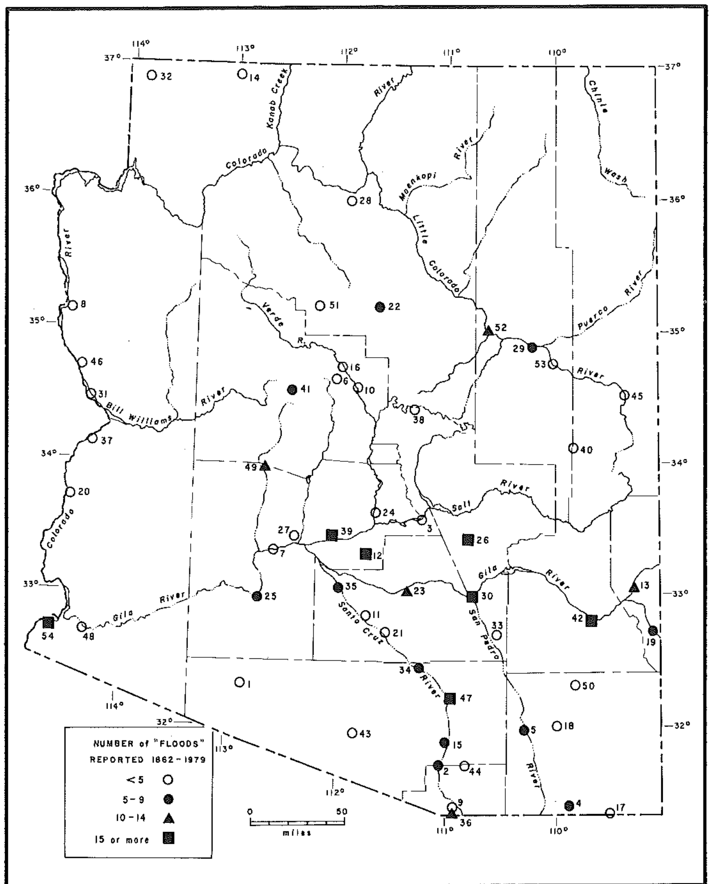


Figure 1B. Frequency of damaging runoff events. The average (7.26 per five-year interval) for the entire historical record has been consistently exceeded since 1925.



- 1. Ajo
- 2. Armado-Tubac
- 3. Apache
- 4. Bisbee
- 5. Benson
- 6. Bridgeport
- 7. Buckeye
- 8. Bullhead City
- 9. Camp Little
- 10. Camp Verde
- 11. Casa Grande
- 12. Chandler-Gilbert
- 13. Clifton
- 14. Colorado City
- 15. Continental
- 16. Cottonwood
- 17. Douglas
- 18. Dragoon
- 19. Duncan
- 20. Ehrenburg
- 21. Eloy
- 22. Flagstaff
- 23. Florence
- 24. Ft. McDowell
- 25. Gila Bend
- 26. Globe-Miami
- 27. Goodyear
- 28. Grand Canyon
- 29. Holbrook
- 30. Kevin & Vicinity
- 31. Lake Havasu City
- 32. Littlefield
- 33. Mammoth
- 34. Marana
- 35. Maricopa
- 36. Nogales
- 37. Parker
- 38. Payson
- 39. Phoenix & Vicinity
- 40. Pinetop
- 41. Prescott
- 42. Safford & Vicinity
- 43. Sells
- 44. Sierra Vista
- 45. St. Johns
- 46. Topock
- 47. Tucson
- 48. Welton
- 49. Wickenburg
- 50. Willcox
- 51. Williams
- 52. Winslow
- 53. Woodruff
- 54. Yuma

Figure 2. Damaging runoff events reported at population centers in Arizona, 1862–1980.

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*Floodplain: "Relatively flat area or lowland adjoining the channel of a stream or watercourse and subject to overflow by floodwaters." Army Corps of Engineers Flood Plain Information Study for Maricopa County, Arizona, Vol. IV Wickenburg Report, app. 2, at 2 (1965).

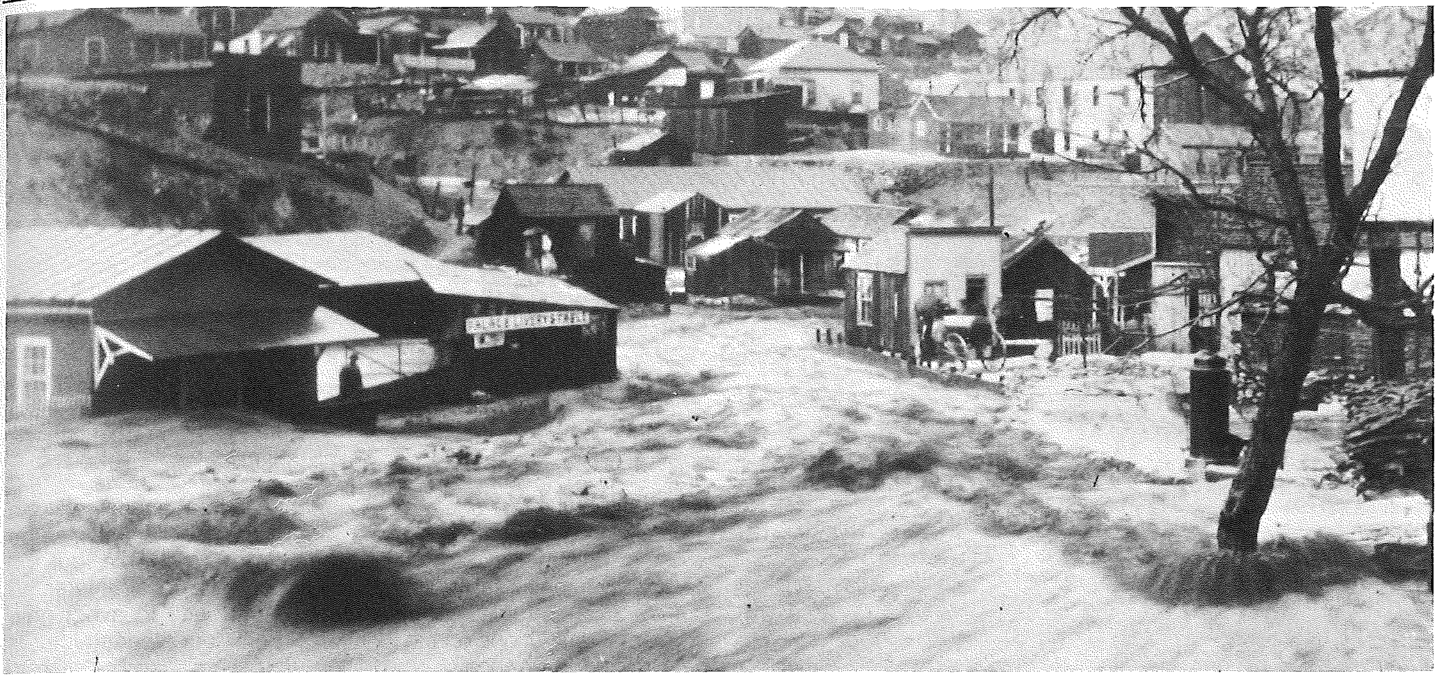

Figure 3A. Flash 'flooding' in canyon near Bisbee, 1897. Photo courtesy of Bisbee Council on the Arts and Humanities, Shatuck Memorial Archival Library, Douglas Collection, Bisbee.

stream flow, homes or other structures built near the eroding side of a meander are repeatedly threatened with the collapse and loss of foundation material and/or supporting ground. Many examples of poorly sited housing exist in Arizona where natural stream erosion processes were either not understood or, possibly, not acknowledged during planning and construction. Portions of some of these developments have already experienced damage and property loss. Results of one study (Slezak, 1980) along the Rillito River in Tucson indicate that channels can migrate locally as much as 818 meters (2,684 feet) horizontally during single high-flow events (e.g., winter storms of 1965 and December 1978). Losses due to lateral erosion may include houses, trailers, roads, water wells, sewer lines, and bridges. Slezak concluded that bank erosion historically has been a more serious problem along the Rillito than has overbank flooding.

3) Downcutting or channel scour has caused much damage to roads, bridge piers, pipelines and other structures located within channel beds. Any obstruction, whether man-made or the river's own debris deposits, impedes the free flow of water and initiates scour and fill processes (Figure 4). In addition, saturated portions of the channel sand itself may flow during peak runoff periods. The thickness of channel material which actually flows may be several times the depth of water in the channel. Thus, during peak flow, bridges with relatively shallow footings may lack support (Figure 3D). Damage to bridge foundations may not be apparent after a storm because channel materials are no longer in motion, and depth of recent scour throughout the channel is not exposed.

Risks associated with true *flooding* include damage from standing or slowly moving water outside of channels (Figure 3E). Rotting of crops, ruined furniture and floors and unwanted silt deposits are examples of flood effects. Sheetflow, i.e., non-channelized water or mud flowing rapidly across the land surface, can present great soil erosion problems and basic water damage to homes or other properties.

Relief efforts, control measures and other policies associated with hydrologic risk mitigation have been the responsibility of many levels of government, as well as the private sector (Table 1). However, complex economic, political and social issues have

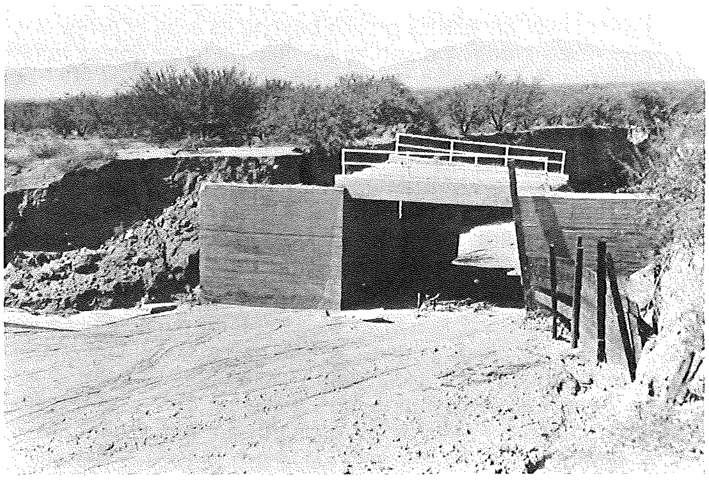

Figure 3B. Channel migration around newly constructed bridge over Palo Alto Road, southern Pima County, 1934. Photo courtesy of University of Arizona Library, Special Collections, Tucson.

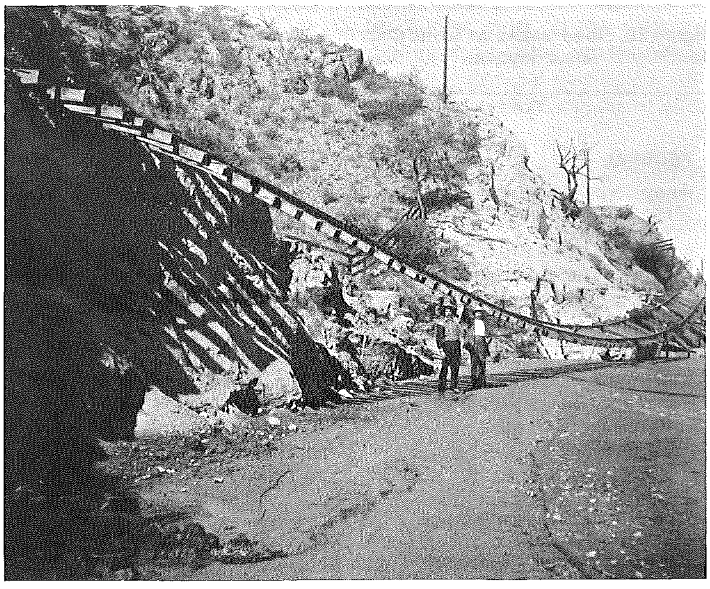

Figure 3C. Bank erosion left the Southern Pacific Railroad track dangling at Tucson, late 1800s. Photo courtesy of University of Arizona Library, Special Collections, Tucson.

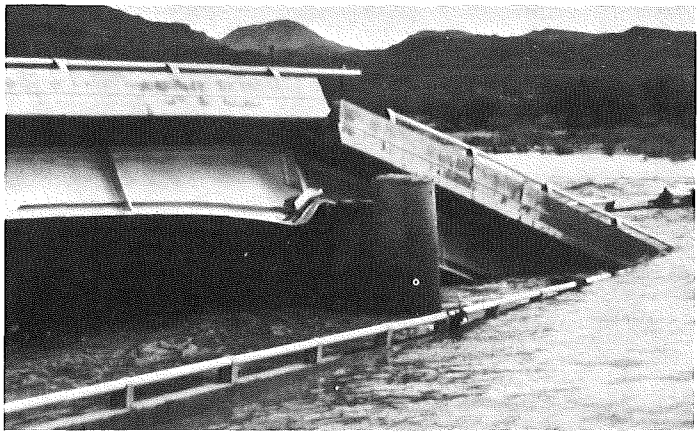

Figure 3D. I-17 bridge collapse on Agua Fria River, December 1978. Six deaths resulted from this event. Photo courtesy of Joe Gonzales, Soil Conservation Service, Prescott.

Figure 3E. Flood waters on Santa Cruz River floodplain, October 1977. Photo courtesy of Vance Haynes.

TABLE 1

FEDERAL

Army Corps of Engineers
(Federal) Emergency Management Administration
Forest Service
Geological Survey
Housing and Urban Development
National Guard
Park Service
President
Soil Conservation Service
Water and Power Resources Service
Weather Service

STATE

(Office of) Economic Planning and Development
(Div. of) Emergency Services
Governor
(Dept. of) Health Services
Highway Patrol
Legislature
(Dept. of) Transportation
(Dept. of) Water Resources

LOCAL

City and County Engineers
Council of Governments
Fire Departments
Hospitals
Planning and Zoning Commissions
Police
Sheriffs
Town Councils

PRIVATE OR VOLUNTEER

Citizens
Consultants
Contractors
Developers
Red Cross

Table 1. Agencies or Groups Involved in Water Management and Relief Efforts.

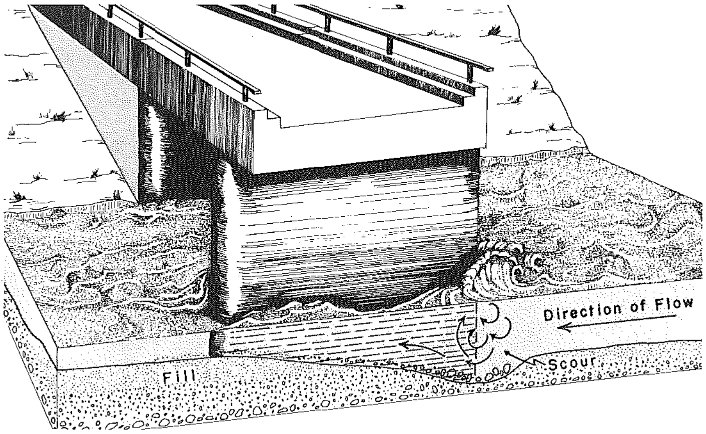

Figure 4. Diagram of scour and fill processes around an obstruction.

tended to inhibit any one agency or authority from either making a comprehensive judgement or providing a thorough solution to the problem. Elimination of hydrologic damage is possible, but the necessary measures might not be acceptable to all interested parties. For example, certain groups might seek to avoid governmental restrictions on the location of homes or other structures near drainage channels. In addition, taxpayers may not wish to bear the cost of a large dam built to protect property located in the predictable path of potential runoff. Conflicts of interest are often a real issue in geologic hazards mitigation.

Runoff control can generally be categorized as corrective (active) or preventive (passive). Corrective measures include dams, levees, channel straightening, storm sewers and concrete reinforcement of banks—all designed to contain and control potential flood waters and minimize damaging effects of erosion. Preventive measures, such as building codes and zoning ordinances, are planned to regulate development within floodplains and to assure maintenance of a channel sufficient in size to carry potential runoff. An excerpt from an article on Arizona "flood" control (Rooney, 1973) summarizes the need for preventive measures coordinated with corrective projects:

> *"Flood control projects are usually expensive, and the protection they afford is limited by the project's design characteristics. Very few, if any, works are constructed to withstand the maximum possible flood, and it is dangerous to assume that an area will ever be completely protected. Although a flood control project may reduce or eliminate the possibility of damage from minor floods, it may also encourage additional floodplain development. Thus, growing communities may unwittingly discover that they are continually expanding into unprotected areas. To some extent, then, the corrective project itself stimulates growth beyond its area of protection and helps create the setting for new damage unless additional corrective measures are undertaken.*
>
> *While corrective measures are extremely costly and almost always require federal financing, preventive measures require very little capital outlay. Because preventive regulations are matters solely of state and local concern, they may be implemented much more quickly and easily than projects requiring federal participation. Most importantly, preventive measures restrict rather than stimulate development in unprotected floodplain areas."*

Another potential problem involves conflicting multiple uses for corrective projects, such as dams. For instance, flood control and water supply objectives cannot both be met without great compromise. Simply illustrated, an empty reservoir can best accommodate flood waters; a full reservoir can best provide irrigation and other water needs. Ironically, these two purposes are often cited together in water plans to justify costs of large projects.

It appears that widespread and frequent damage from hydrologic events in Arizona is increasing, unabated (Figures 1 and 2). The corresponding surge of urban growth (six-fold) and increased property losses since 1940 (Figure 1A) can be attributed to the increase in building and occupancy of lands highly susceptible to runoff hazards. Further development of such areas appears inevitable as long as floodplains and, often, channel *beds* and *banks,* remain inexpensive, unrestricted areas in which to build.

• • •

The homeowner can use a few common sense measures for protection from risky property investments:

1. Visit the nearest USGS or local geological survey office and discuss the topography of your site. Where are the nearest drainage conduits? How susceptible is the site to flooding, bank erosion, etc.?
2. Obtain an air photo of the land surrounding your site from the city planning office or Soil Conservation Service. A sequence of photos taken over a 30–50 year period would be preferable. Check especially for stream migration patterns which may adversely affect your property.
3. Talk to neighbors about water damage history in your neighborhood. Have the streets and houses flooded? Do ponds collect in the yards for days after a rainstorm? Visit the site during or immediately after rainstorms to see if and where water collects or erodes the property.
4. Take a walking tour of surrounding land. Are drainageways that lead in and out of a new subdivision adequately connected through the property? Have natural drainage patterns been modified? Discover if your site included a former channel and was altered by terracing, bulldozing or landscaping.
5. Check insurance companies for the flood-prone status of your site.
6. If your investigations lead you to suspect the safety of your site, and you still wish to build, hire a professional consultant (geologist, hydrologist or engineer) to study your specific site needs and to offer technical advice.

• • •

REFERENCES

Slezak, M. H., 1980, Bank erosion as a socio-geologic hazard along the Rillito River, southeastern Arizona: Univ. of Ariz. Dept. of Geosciences 8th annual Geoscience Daze Abst., p. 31.

Rooney, M. R., 1973, Flood control and Arizona: Law and Soc. Order, *4,* p. 919–937.

NEW MAP

A depth-to-bedrock map of the basins in the Basin and Range Province of southern Arizona has recently been completed by Joan M. Oppenheimer and Dr. John S. Sumner through a grant from the USGS. The depth-to-bedrock values were modeled from residual gravity data based on 20,000 gravity stations using an iterative, 2-D model. The modeling program accounts for variations in the density of basin fill and the density of known salt bodies. Well data were used to refine the contours shallower than 2,000 feet.

Much of the study area is unexplored. This map provides a means for initial assessment of groundwater, mineral and other resources in southern Arizona. The 15 plotted quadrangles include: Kingman, Williams, Needles, Prescott, Salton Sea, Phoenix, El Centro, Ajo, Lukeville, Nogales, Tucson, Mesa, Clifton, Silver City and Douglas.

The map is available at the same scale as the Geologic Map of Arizona (1:500,000) at $25.00 each. Blacklines are available at 1:250,000 at $5.00 for each of the 15 quadrangles. The maps are published by and available from the Lab of Geophysics, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721.

New Earth Science Exhibit

by Peter Kresan

The Arizona-Sonora Desert Museum, internationally known for its fine natural history exhibits, is finishing Phase II of the Earth Sciences Center with unique and exciting exhibits, summarizing the geology and life history of our region.

The uniqueness and dynamic history of the Sonoran Desert are the main themes for the new exhibits. Its Basin and Range landscape is blanketed with unusual and sometimes bizarre plants, inhabited by incredible desert creatures and endowed with rich mineral resources. The landscape is geologically new (within the last 15 million years) and very dynamic, but also contains evidence for very different and fascinating past environments (from shallow seas to violent vulcanism).

The dynamics of the earth's surface will be illustrated by the Orb, a spherical movie screen presentation, which will show the continents drifting across the earth through geological time. The orb will be surrounded by an oval exhibit wall, depicting the geologic evolution of our region, and representing a sweep through earth history. Specimens of rocks, minerals, fossils and living plants and animals will focus attention on the Sonoran geologic and life story. As a backdrop to the specimens, images will characterize the paleoenvironments in which the life existed and rocks and minerals formed.

Most exhibits will be open—without glass—and many specimens will be touchable. There will be no walls arbitrarily dividing geologic and life history. In this manner, the historical development of the Sonoran Desert region may be viewed as a continuum of interrelated geologic and life processes and events; it will also illustrate our unique position in the whole scheme of things. Such an open and integrated approach is in the tradition of the Museum's exciting and innovative exhibit technique.

The formation of Arizona's rich porphyry copper deposits within the heart of volcanoes is one of the important stories woven into the geologic history exhibits. A rich display fo Arizona-Sonora minerals will be exhibited in a jewel-like room, focusing on the themes of minerals and natural resources, and on the region's special significance as a commercial mining center, emphasizing copper. Visitors will become aware of the special geological circumstances that occurred through time, and which now allow us to mine these valuable mineral deposits.

You will be able to follow the progress of the Phase II exhibits in the Earth Science Center during your visits to the Desert Museum. Scheduled completion is for the fall of 1981. The Arizona-Sonora Desert Museum is looking forward to the day when the geologic story will set the stage for a better understanding of the natural history of our Sonoran Desert.

The capital campaign to fund Phase II is on schedule and on budget (in 1980 dollars) with 47% of total project cost received to date, or $315,000. An important component of this funding is the largest corporate grant ever received by the Desert Museum, a $75,000 challenge grant from the Anaconda Copper Company, Atlantic Richfield Foundation. Other major supporters are ASARCO, Inc., and Duval Corporation, Pennzoil Company.

Peter Kresan is a geologist who serves as a consultant to staff at the Desert Museum. He also teaches geology at the University of Arizona.

Bureau Activities Summary: Fiscal Year 1979-1980

by Larry D. Fellows

An understanding of Arizona's geologic framework and mineral resources has never been needed more than now. Requests for geologic information relative to urban development, agriculture, highways, mineral exploration, mining, recreation, waste disposal and other uses are increasing. Many land-use decisions could be made more efficiently if the surface and subsurface distribution of earth materials and conditions were known.

Objectives of the Arizona Bureau of Geology and Mineral Technology are to inform the public, encourage the wise use of land and mineral resources, and provide technical advice and assistance on the geologic setting, mineral resources and geologic factors that affect land use.* In order to accomplish this, Bureau scientists must continue to learn about the geology and mineral resources of the state by making inventories of a diversity of earth materials, making studies of their characteristics, and by collecting and evaluating data (rock cuttings and cores, published and unpublished maps and reports, etc.)

Activities of Bureau personnel directed toward meeting these responsibilities during the fiscal year 1979–1980 are described and summarized below.

Information and Assistance

Information is made available to the public by (1) publishing geologic, mineral resource and other maps, as well as the results of geologic studies, (2) keeping unpublished data on open file, (3) answering written and telephone inquiries, (4) assisting visitors, and (5) preparing a quarterly newsletter, *Fieldnotes*.

During the year, publications sales totaled nearly $19,100, compared with $17,400 for the preceding year. More than 2,400 persons visited our offices, and many more telephoned or wrote for assistance. These requests increased substantially over the previous year.

Geologic Framework

Geologic maps and cross sections are used to show the geologic setting of the state. These maps show not only the distribution of rock and unconsolidated materials, but also, depending on scale, where folding, tilting, fracturing or displacement by faults have occurred. A cross section is an interpretation of how a hypothetical slice through the earth would appear. The fundamental importance of the third dimension—the structure and dynamics of the earth beneath our feet—is all too often forgotten until an occurrence like Mt. St. Helens reminds us that this earth is not inanimate.

An anticipated Bureau project is an up-to-date, more detailed geologic map of the state. The current map, printed in 1969, is based largely on reconnaissance mapping that was done during or prior to the 1950s. Making a new, more detailed state map will be a major effort requiring careful planning and many months of work. The first step is in progress—collecting all available geologic maps and preparing an index designed to indicate those parts of the state that need additional mapping attention.

A map showing unconsolidated materials (alluvium, sand dunes, landslide deposits, talus, etc.) is being prepared with financial assistance from the U.S. Geological Survey (USGS). The scale of the map will be 1:1,000,000 (one inch on the map equals 16 miles on the ground).

Work on the state gravity map at a scale of one inch to eight miles and a contour interval of five milligals is nearing completion. A series of more detailed gravity maps are also being prepared at a scale of 1:250,000 (one inch equals four miles) and a contour interval of two milligals. These maps are being completed as part of the Bureau's geothermal assessment project and in cooperation with the University of Arizona Geosciences Department, with funding from the U.S. Department of Energy (DOE).

Mineral and Energy Resources

Arizona has led the nation in production of copper for many years. Approximately 65% of the copper produced in the U.S. comes from Arizona mines. Copper also accounts for more than 80% of the total annual mineral value produced in Arizona. In terms of metal production (copper, molybdenum, silver, gold, lead, zinc, etc.), Arizona leads the nation. In terms of the value of all mineral commodities produced (metals, non-metals or industrial minerals, mineral fuels), the state ranks about tenth. Industrial minerals produced in Arizona include asbestos, cement, clays, gypsum, halite, lime, pumice, sand and gravel, stone, feldspar, fluorspar, perlite and zeolites. Coal and crude oil are fuels produced in the state.

Current Bureau projects include research on the relationships between the occurrence of metals, the chemistry of the igneous rocks to which they relate, and plate tectonics, i.e., the dynamics of earth structures. Various compilations are in progress: An inventory of known molybdenum occurrences (funded by the USGS) has been completed; a study of other elements, also funded by USGS, has just begun; and a research project on all known uranium occurrences is being implemented with funding from the DOE. One Bureau geologist has been a participant in a University of Arizona Geosciences Department project, funded by DOE, to evaluate the potential for uranium in certain crystalline rocks. The Bureau is also studying the geology of Arizona's industrial minerals, with most recent emphasis on evaporite deposits (salt, gypsum).

Active mineral technology projects include the recovery of minerals from mine dumps in Mohave County (funded by the U.S. Bureau of Mines), and a study of metal recovery from super alloy scrap.

A statewide assessment of potential geothermal resources, funded by the DOE, is in its fourth year. To date, 37 areas have been identified that are believed to have geothermal potential. More detailed studies are being conducted in seven areas. In addition, a Geothermal Resource Map of Arizona is being prepared at a scale of 1:500,000 (one inch equals eight miles). The U.S. Department of Water And Power Resources Service, formerly the Bureau of Reclamation, funded an assessment of the geothermal potential in the Phoenix-Casa Grande area.

Impact of Geologic Factors

Year-in and year-out, hydrologic activity (flooding, etc.) is the most devastating natural hazard in Arizona. The Phoenix region, for example, has experienced "100-year floods" for three successive years. However, the *potential* for damaging earthquakes capable of affecting parts of Arizona may have been underestimated. Land subsidence due to the pumping of groundwater is becoming increasingly serious. In parts of central and southeastern Arizona, water levels have been lowered by more than 200 feet since the 1950s because of groundwater withdrawal. This lowering has been accompanied locally by subsidence of six to 12 feet.

Identification of areas having potential geologic hazards or limitations is based on knowledge of the geologic framework, including rock and unconsolidated materials present at the surface and

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*Arizona Revised Statutes, Title 27, Chap. 1.

in the subsurface, depth to bedrock, type of materials present, location of faults and fractures, groundwater conditions, topographic characteristics and processes of erosion and deposition. This requires field observation, data collection, geologic mapping analysis of drill hole records and other procedures to get the basic data on which evaluations, interpretations, decisions and applications can be based.

Work in progress includes the preparation of a catalog of earthquakes of historic record and an epicenter map (funded by the Nuclear Regulatory Commission and the USGS), a report of the 1887 Sonora (Mexico) earthquake (the strongest recorded quake to be felt in Arizona), and a statewide assessment of potential geologic hazards, funded by USGS.

The final two maps of a 10-map series on applied geology in the McDowell Mountains area in suburban Phoenix were drafted and published by the Bureau. Field work for this project was done by geologists at Arizona State University.

If you would like more detailed information about Arizona's geology and mineral resources, Bureau projects in progress, operations, maps and reports for sale or open file information, please write or call. Better yet, stop in and talk with our staff, and, while you're here, have a look at our expanded and renovated facilities.

MMRRI Programs

by *Orlo E. Childs*

The Arizona Mining and Mineral Resources Research Institute (MMRRI) is directed by Orlo E. Childs as part of the organizational structure of Dean William H. Dresher. Dean Dresher is director of the Bureau of Geology and Mineral Technology and Dean of the College of Mines.

Now in its second year of existence in the College of Mines at the University of Arizona, the Institute has made progress toward its principal objective of supporting and enhancing the research and academic programs pertaining to mining and mineral engineering and science. The Arizona MMRRI is one of 31 state institutes where mineral resource academic programs have qualified for federal support through the Office of Surface Mining of the Department of the Interior. The directors of these institutes will hold their second annual meeting at the University of Arizona in December of 1980.

The Mine Reclamation Center (MRC) is an integral part of the MMRRI. In its first year, MRC research was funded at approximately $150,000, and during 1980–1981, research funding will increase to $250,000.

Five sophomore scholars will be assisted by their second MMRRI scholarships, during the 1980–1981 class year. MMRRI fellowships also help support eight post-graduate students who are working in the University of Arizona Departments of Mining and Geological Engineering, Metallurgical Engineering, Renewable Natural Resources, and Chemical Engineering.

To aid the mineral resource related programs of the University, five outstanding engineers and scientists have been appointed as MMRRI post-doctoral research associates:

Dr. Martin Karpiscak from the University of Arizona, Mine Reclamation Center;

Dr. P. K. Chatterjee from the University of Queensland, Australia, Department of Mining and Geological Engineering;

Dr. Werner Hahn from the University of Arizona, Department of Chemical Engineering;

Dr. Anders Sellgren from Chalmers University of Technology, Göteborg, Sweden, Department of Metallurgical Engineering; and

Dr. Gerald Harwood from the University of Arizona, School of Renewable Natural Resources.

In a nationwide competition involving all 31 MMRRI institutes, five research proposals from faculty of the University of Arizona were selected for funding by the Office of Surface Mining. These proposals from the College of Mines were:

1. Smelter Emission Controls: The Impact of Mining and Market for Acid, Professor Michael Rieber, Department of Mining and Geological Engineering: $78,750.—one year.
2. Ground and Air Vibrations Caused by Surface Blasting, Assistant Professor Jaak J. Daemen, Department of Mining and Geological Engineering: $125,276—first of two years.
3. Factors Affecting Flotation Recovery of Molybdenite and Porphyry Copper Ores, Assistant Professor Srinivisan Raghavan, Department of Metallurgical Engineering: $40,327—one year.
4. Characterization and Processing of Coal Fired Copper Reverberatory Flue Dusts, Assistant Professor Srinivisan Raghavan, Department of Metallurgical Engineering: $36,782—one year.
5. Inventory of Hazards of Mineral Lands, Using Satellite Imagery and Collateral Data, Assistant Professor C. E. Glass, Department of Mining and Geological Engineering, and Assistant Professor R. A. Schowengerdt, Department of Systems Engineering: $21,357—second year of two-year project.

Recent contracts have been formalized to fund the third year of Arizona MMRRI activities. It is hoped that even more contributions to research and mineral resource education will be forthcoming.

ABSTRACTS

The following abstracts on Arizona geology were included in the program for the 93rd Annual Meetings sponsored by the Geological Society of America on November 17–20, 1980 in Atlanta.

The evolutionary nature of alteration, mineralization, and fluid characteristics in intrusion-related porphyry copper deposits of the southwestern United States: Beane, Richard, AMAX Exploration, Inc., Tucson, AZ.

The role of micro-organisms in the formation of desert varnish and other coatings: SEM study: Borns, David J. and others, Dept. of Geological Sciences and Dept. of Microbiology, Univ. of Washington, Seattle, WA.

Distribution and petrogensis of topaz rhyolites, western USA, Burt, Donald M.; Bikun, James V.; Christiansen, Eric H., Dept. of Geology, Arizona State Univ., Tempe, AZ.

Early Triassic stratigraphy and depositional history of the cordilleran miogeosyncline: Carr, Timothy R., Dept. of Geology and Geophysics, Univ. of Wisconsin, Madison, WI.

Regional geologic events inferred from upper proterozoic rocks of the North American cordillera, Christie-Blick, Nicholas and others, Dept. of Geological Sciences, Univ. of California, Santa Barbara, CA.

The relationship between lithofacies and Ichnofauna in shallow marine deposits of the Kaibab Formation, Northern Arizona: Decourten, Frank L., Dept. of Geology and Geophysics, Univ. of Utah, Salt Lake City, UT.

Hydrocarbons in mantle derived amphiboles, Grand Canyon area, Arizona: Garcia, M.O. and others, Hawaii Institute of Geophysics, Univ. of Hawaii, Honolulu, HI.

The regional potential of argillaceous strata in the United States for radioactive-waste disposal: Gonzales, Serge, Institute of Natural Resources and Dept. of Geology, Univ. of Georgia, Athens, GA; Johnson, Kenneth S., Oklahoma Geological Survey and Univ. of Oklahoma, Norman, OK.

Geochemistry of sericites in porphyry deposit alteration assemblages: Guilbert, John M., Dept. of Geosciences, Univ. of Arizona, Tucson, AZ.

Land subsidence and ground failure induced by fluid withdrawal in urban areas: Holzer, Thomas L., USGS, Menlo Park, CA.

Overconsolidation of clastic aquifer systems in areas of man-induced land subsidence: Holzer, Thomas L., USGS, Menlo Park, CA.

Method for estimating land subsidence in south-central Arizona: Pawelik, David W.; Laney, Robert L.; Bales, James T., USGS, Phoenix, AZ.

Is there a Casa Grande bulge and will it cause earthquakes in Arizona?: Raymond, Richard H.; Cordy, Gail E.; Tuttle, Gregory M., U.S. Water and Power Resources Service, Phoenix, AZ.

Mineralogy of the U and Th sites in a uraniferous precambrian granite: Woodhead, James A. and others, Div. of Geological and Planetary Sciences, California Inst. of Technology, Pasadena, CA.

U-Th-Pb^{rad} isotopic studies in six congenetic mineral species from a uraniferous precambrian granite: Williams, Ian S.; Silver, Leon T., Div. of Geological and Planetary Sciences, California Inst. of Technology, Pasadena, CA.

PAPERS

The Museum of Northern Arizona sponsored the 33rd annual Symposium on Southwestern Geology, August 29, 1980. Seventeen persons presented papers, the titles of which are listed below. Anyone who has questions or desires additional information about the presentations should contact the author(s) directly.

Preliminary paleoecologic interpretation of the Green horn marine cycle (Cretaceous) in the area of southwestern Black Mesa, Coconino County, Arizona, Dale Nations and James I. Kirkland, Northern Arizona Univ., Flagstaff.

Oak Creek-Grand Canyon Permian correlations–preliminary reflections, H. W. Peirce, Bureau of Geology and Mineral Technology, Tucson.

Century-long changes in the fluvial system of the Henry Mountains region, Utah, William L. Graff, Dept. of Geography, Arizona State Univ., Tempe.

On the growth and form of the Cretaceous oyster Pycnodonte Newberri (Stanton), Teresa Bone and Karl Flessa, Dept. of Geosciences, Univ. of Arizona, Tucson.

Petroleum exploration–results of recent wildcats in catron and Socorro Co., New Mexico–with implications on oil and gas potential, Bruce A. Black, Colorado Plateau Geological Services, Inc., Farmington, NM.

Late Cenozoic displacements along the Verde Fault, southern Verde Valley, Edward W. Wolfe, USGS, Flagstaff.

Collapse features of the Mogollon Rim region, Ralph E. Weeks and Donald G. Metzger, Tempe.

Development of deep in situ soil moisture determination technique, Sheldon D. Clark, Tucson.

Topographically controlled dune systems of earth (Navajo Reservation) and mars, Morgan Gray, Camilla K. McCauley and William J. Breed, Museum of Northern Arizona, Flagstaff.

Geology of Castle Hot Spring, Ken Wohletz, Arizona State Univ., Tempe.

New observations of the stratigraphy and paleontology of the Verde Formation, Dale Nations, Richard Hevly and Jerry Landye, Northern Arizona Univ., Flagstaff.

The Paleozoic-Precambrian uncomformity in central Arizona, L.P. Knauth and Ed. Stump, Arizona State Univ., Tempe.

Paleonotological inventory of the Statelands Bisti Coal Mine, San Juan County, New Mexico, D.LeMone, A. Harris, D. Wolberg and R. Simpson, Univ. of Texas at El Paso.

Paleontological inventory, La Plata Coal Mine, San Juan County, New Mexico, D. LeMone, A. Harris, W. Cornell and R. Simpson, Univ. of Texas at El Paso.

Interim report: the hydrology and climatology of the Skunk Creek archaeological site (NA-15909) during Hohokam time, Richard A. Earl, Arizona State Univ., Tempe.

Magma flow, heat losses and brecciation of host rocks during dike emplacement, Ship Rock, New Mexico, Paul Delaney, USGS, Flagstaff.

Calcite analysis determination of dominant stress field, Slate Mountain, Arizona, Alan P. Trujillo and Karl J. Schmid, Northern Arizona Univ., Flagstaff.

The Museum of Northern Arizona sponsors these symposia so that the results of work in progress or work nearing completion can be made known to and discussed by others who might have familiarity with this subject. Abstracts are not requested. Plans are being made for the 34th symposium which will be held in late August or early September 1981. Additional information about the symposium will be included in future issues of *FIELDNOTES.*

Fieldnotes

Volume 10, No. 4 December 1980

State of Arizona .... Governor Bruce Babbitt
University of Arizona .... President John P. Schaefer
Bureau of Geology & Mineral Technology
Director .... William H. Dresher
State Geologist .... Larry D. Fellows
Editor .... Anne M. Candea
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