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FIELDNOTES

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Radon Gas: A Geologic Hazard

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Low-level radiation is common in the natural world—a fact of life that no one can completely avoid. Much of this natural background radiation is produced by radioactive isotopes in rock, soil, or their derivatives such as concrete, brick, and cinder block. Another source of background radiation is cosmic rays, which strike the Earth from outer space. Naturally occurring radioactive isotopes, such as carbon-14 in the atmosphere and potassium-40 in soil, are absorbed by plants, then passed on to animals through the food chain to become internal sources of radiation.

Background radiation has generally been considered an insignificant health hazard because the level of exposure due to most natural sources is small. In the past few years, however, it has become apparent that radon gas, a radioactive decay product of uranium, is present in virtually all homes and buildings, and in some cases, in hazardous concentrations. Radon gas gradually seeps from soil, fractured rock, and building materials derived from them. Because it is chemically inert and forms no natural chemical compounds, radon can travel through permeable materials without adhering to them. Radon-222 has a half-life of 3.8 days and decays to radioactive daughter products that readily form chemical bonds. Homes can be effective traps for radon gas derived from underlying rock and soil, especially when these materials are permeable and contain higher than normal concentrations of uranium.

Radiation exposure to human lung tissue results from inhalation of radioactive radon-decay products that adhere to lung tissue or to airborne particles that become trapped in the lungs. Due to inhalation of these products, the lungs of most people receive more radiation than any other body organ (NCRP, 1984b). High radon levels in underground mines are a known cause of lung cancer in miners (NCRP, 1984a). Based on recent findings of higher-than-expected indoor-radon levels, the U.S. Environmental Protection Agency estimates that 5,000 to 20,000 people in the United States die of lung cancer each year due to inhalation of radioactive radon-decay products, compared to an estimated 85,000 deaths per year due to smoking (EPA, 1986).

Radon is considered to be a geologic hazard because it originates from geologic materials and because the amount of uranium in underlying rock and soil is a major factor influencing indoor-radon concentrations. Knowledge of the distribution and nature of "uranium-rich" rocks is helpful in locating areas where radon is a possible health hazard. The term "uranium-rich," as used in this article, refers to rocks that contain more than 10 parts-per-million (ppm) uranium, or about three times the crustal average for granitic rocks. In contrast, uranium ore contains more than 1,000 ppm uranium. Uranium-rich rocks are present at numerous localities in Arizona. Based on indoor-radon-concentration studies from other States that contain large areas of uranium-rich rock, a small percentage of Arizona homes can be expected to have radon levels high enough to be considered hazardous.

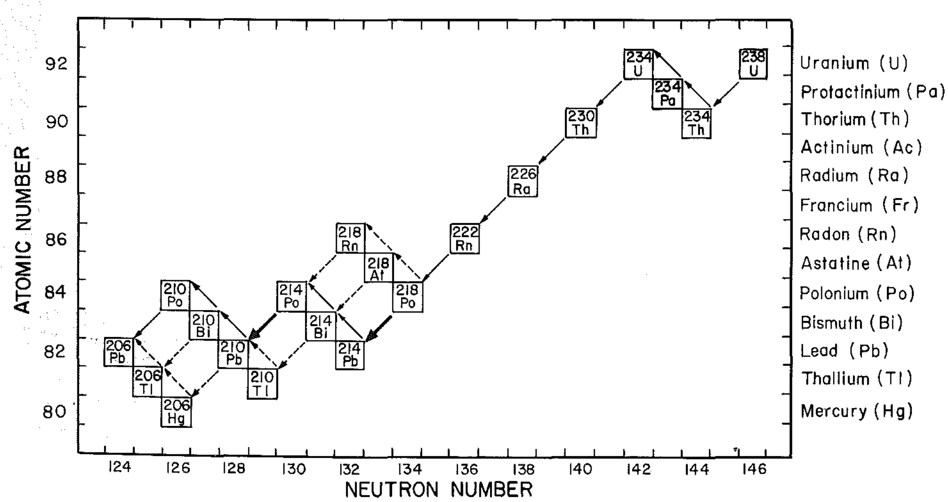

Figure 1. Decay path of uranium-238 to stable lead-206. Each box represents an isotope produced in the uranium-238 decay series. Atomic number plotted on vertical axis corresponds to number of protons in nucleus; neutron number plotted on horizontal axis corresponds to number of neutrons in nucleus. Isotope number in each box is sum of atomic number (proton number) and neutron number. Arrows pointing down-to-left represent alpha decays; arrows pointing up-to-left indicate beta decays. Heavy solid arrows are the two alpha decays that by far cause the greatest damage to lung tissue due to inhalation of airborne radon-decay products. Dashed arrows are decay paths followed by a small fraction of decays (less than 1 percent). Modified from Faure (1977).

Radiation: What Is It?

Each of the 103 known chemical elements consists of several isotopes. Each isotope of a particular element has the same number of protons, but different numbers of neutrons, and thus, different atomic weights. Some of these isotopes are radioactive. Carbon-14, for example, is a radioactive isotope of

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Table 1. Half-lives, alpha-decay energies, and maximum beta-decay energies of uranium-238 decay series. Gamma-ray energies are generally less than maximum beta-decay energies and are only significant for decay of lead-214 and bismuth-214. MeV = million electron volts.

Radio-nuclide	Half-Life	Alpha Energy (MeV)	Maximum Beta Energy (MeV)
^{238}U	4.5 billion years	4.1-4.2	—
^{234}Th	24 days	—	0.06-0.2
^{234m}Pa	1.2 minutes	—	2.3
^{234}U	250,000 years	4.7-4.8	—
^{230}Th	80,000 years	4.6-4.7	—
^{226}Ra	1,600 years	4.6-4.8	—
^{222}Rn	3.82 days	5.5	—
^{218}Po	3.05 minutes	6.0	—
^{214}Pb	26.8 minutes	—	0.7-1.0
^{214}Bi	19.7 minutes	—	0.4-3.3
^{214}Po	16 milliseconds	7.7	—
^{210}Pb	22 years	—	<0.1
^{210}Bi	5 days	—	1.2
^{210}Po	138 days	5.3	—
^{206}Pb	stable	—	—

carbon that has a half-life of approximately 5,700 years. This means that in 5,700 years half of the atoms of any given quantity of carbon-14 will undergo radioactive decay and be transformed into another isotope (in this case nitrogen-14). It is the process of radioactive decay that produces most of the radiation at the Earth's surface.

Three different types of radiation associated with radioactive decay are termed gamma, beta, and alpha. Gamma rays, a very high-energy and extremely short-wavelength form of electromagnetic radiation (light and radio waves are lower energy, longer wavelength forms), have the greatest penetrating ability. Gamma rays from space can penetrate the atmosphere and reach the Earth's surface. Beta particles produced by beta decay are high-energy electrons that have moderate penetrating ability. Alpha particles produced by alpha decay are each composed of two protons and two neutrons and, because of their large size and positive charge (+2), have the least penetrating ability of all the radiation types. An alpha particle produced by typical alpha decay will travel only a few centimeters through air before it is stopped by collisions with air molecules. Alpha radiation from external sources is generally insignificant, but when produced within the body, it can be a major cause of radiation exposure. An alpha particle is a helium nucleus. Helium is steadily produced by alpha decays in the Earth, locally resulting in economic concentrations of underground helium gas. (See Spencer, 1983, for more on helium).

Origin of Radon

Most of the rock in the Earth's crust, as well as soil and alluvium derived from it, contains one to several parts-per-million uranium. About 99.3 percent of this uranium is the isotope uranium-238, which has a half-life of about 4.5 billion years (approximately the age of the Earth). Decay of a uranium-238 atom marks the beginning of a series of 14 decays that end at the stable isotope lead-206 (Figure 1; Table 1). The decay product of an individual parent isotope is called its daughter product. Unstable daughter isotopes are referred to as intermediate daughter products. Radium-226 and radon-222 are intermediate daughter products in the decay of uranium-238 to lead-206. Radium-226, with a half-life of 1,600 years, is the immediate parent of radon-222.

When radium-226 decays to radon-222, it releases a high-energy alpha particle. The alpha particle is like a bullet from a gun and, obeying the laws of physics, the newly formed radon-222 atom undergoes recoil. If the radon atom is near the surface of a mineral grain, it can be knocked out of the grain by recoil. In some materials such as clay, radon is loosely trapped in the mineral's molecular structure and can migrate out without the assistance of recoil. This more gradual process of migration is known as diffusion. Radon atoms are liberated from geologic materials by both recoil and diffusion.

Transport of Radon and Its Decay Products

Radon gas is present in pore spaces in soil and rock as a result of liberation of radon from geologic materials. Radon is an inert gas and, unlike all other uranium-series decay products, does not form chemical bonds. As a result, a radon atom can move freely through the pore spaces of a porous and permeable geologic material without bonding to other mineral grains or substances. The mixture of air, radon, and other gases in underground pore spaces is known as soil gas.

Diffusion of soil gas, or its movement through a permeable soil or fractured rock due to the random movements of gas atoms and molecules, results in transport of radon to above-surface environments or into underground mines. The ability of radon to migrate through soil is highly dependent upon physical properties of the soil. Well-fractured rock and coarse well-drained soils are likely to be highly permeable to radon, whereas clays and muds, particularly if wet, should not permit much radon movement (Tanner, 1986). Radon originating from depths greater than a meter or two in the Earth generally does not reach the Earth's surface because it decays so quickly. As a result, uranium concentration of only the top few meters of the Earth's surface need be considered in evaluating possible indoor-radon levels. Because radon enters the atmosphere at the ground surface, and has a short half-life (3.8 days) and high density, it is not well mixed with the Earth's atmosphere and tends to be concentrated at low altitudes near the land surface. Radon levels may be significantly elevated in valleys or other topographic depressions during periods of atmospheric inversion (Texas Instruments, 1975).

High radon levels most commonly occur in homes and other buildings as a result of upward transport of soil gas from underlying soil and rock. Radon typically diffuses out of underlying soil and into basements, crawl spaces, and lower levels of homes or buildings, eventually reaching upper levels as well. Cracks in concrete floors, open spaces around pipes that enter homes from below ground, joints where floor meets wall, and drainage outlets or sumps can all provide conduits for entry of radon-bearing soil gas into houses. Even microscopic cracks in concrete can greatly elevate permeability to soil gas, although concrete-slab floors that are not cracked are generally good barriers against soil gas. In a few areas where local water supplies are derived from wells in uranium-rich rock and the water is used within a week or two from the time it is pumped from the ground, significant amounts of radon can enter indoor air when the water is exposed to the air within a house, such as in a shower or sink.

It was initially thought that tightly sealed, energy-efficient homes had the greatest potential for high radon concentrations (e.g., Hollowell and others, 1979), but a more recent study suggests that there is little correlation between ventilation rate and radon concentration (Nero, 1986). Possibly the most significant factor affecting radon infiltration

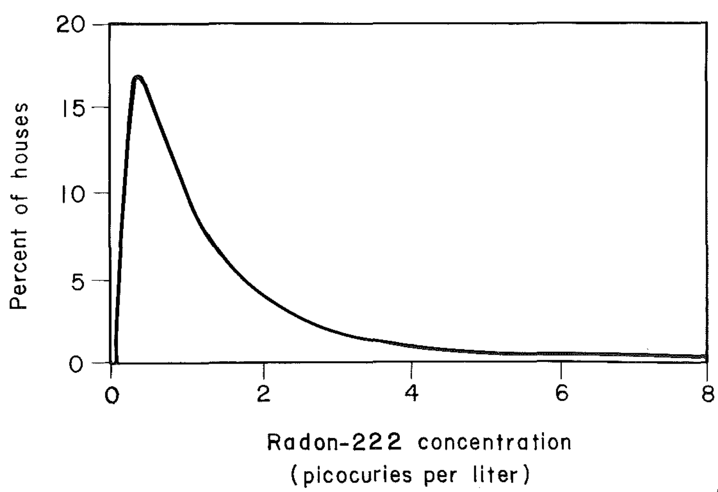

Figure 2. Radon-concentration distribution for homes in the United States. Approximately 2 percent of homes tested had radon levels above 8 pCi/l. From Nero (1986).

into homes is the difference in air pressure between indoor air at ground level and outdoor air. If indoor air pressure is lower, soil gas is effectively drawn up and out of underlying soil and into homes, while outdoor air is drawn downward into surrounding soil. Even if outdoor air travels through soil for only 2 or 3 days before it is sucked into a home, it could acquire a high concentration of radon. Reduced air pressure in basements and the lowest levels of homes results from heating indoor air. Warm indoor air rises to the upper levels of a house, where it builds up positive air pressure that pushes the heated indoor air through cracks and other openings to the outside. At low levels in the same house, air is drawn in through cracks and other openings as a result of lower indoor air pressures. Some homes are remarkably efficient at sucking up soil gas due to air-pressure differences. In contrast, use of evaporative coolers increases air pressure in a home, forcing indoor air downward through cracks and openings and reducing or preventing influx of soil gas.

Approximately 7,000 to 12,000 liters of air are inhaled and exhaled by the average adult every 24 hours. The spontaneous decay of radon while in the lungs is not a major source of radiation because almost all radon is expelled after each inhalation. Polonium-218, the immediate decay product of radon-222, begins a sequence of four decays with a total half-life of about 50 minutes before reaching lead-210, which has a half-life of 22 years (Figure 1; Table 1). Polonium and its daughter products are chemically reactive and typically are highly charged immediately after decay. Newly formed polonium-218 and its decay products tend to adhere to the first solid with which they come in contact, including lung tissue and airborne dust particles that can be temporarily trapped by the lungs. The residence time of individual radon-daughter atoms and dust particles in the lungs is usually longer than the half-lives of the immediate decay products of radon. Two of the four decay steps between polonium-218 and lead-210 are alpha decays that can cause significant molecular disruption in adjacent lung cells because of the large mass and high energy of ejected alpha particles (Figure 1; Table 1).

Radon concentration in air is commonly measured in picocuries per liter (pCi/l), which is actually a measure of the number of nuclear decays over a given time period in a liter of air. One picocurie corresponds to about two decays per minute. Based on a few surveys unevenly distributed across the United States (none of which were from desert areas), it is estimated that most homes contain less than 3 pCi/l and only 2 percent of U.S. homes contain more than 8 pCi/l (Nero, 1986; Figure 2). The U.S. Environmental Protection Agency has established 4 pCi/l as a general guideline for maximum acceptable indoor-radon concentration. The risk of contracting lung cancer due to living in a home with an indoor-radon level of 4 pCi/l is equivalent to smoking almost half a pack of cigarettes per day (Figure 3).

Working level (WL) is defined as any combination of short-lived radon daughters in one liter of air that results in the emission of a specific quantity of potential alpha-particle energy (1.3×10^5 million electron volts). A working-level month (WLM) corresponds to exposure to one working level for a working month (170 hours). The working-level month is a commonly used unit of human radiation exposure due to radon-daughter products in air in underground mines. The U.S. occupational standard set in 1971 is four working-level months per year, with maximum airborne concentration not to exceed one working level (NCRP, 1984a,b). This is approximately equivalent to the amount of exposure that results from being in a home 75 percent of the time with an indoor-radon level of 15 pCi/l.

How Hazardous Is Radon?

Knowledge of the hazards of radon comes largely from studies of uranium miners who were exposed to high levels of radon in underground mines. A lung disease affecting miners who worked in the Joachimstal and Schneeburg mining areas of central Europe was described as early as 1500 A.D. and was recognized as cancer in 1879. The role of radon in causing lung cancer was not suspected until 1932 and not generally accepted until the 1960's. A greater-than-expected rate of lung-cancer deaths among underground miners working in U.S., Canadian, and Czechoslovakian uranium mines, Swedish and British iron mines, Swedish lead-zinc mines, and Newfoundland fluorspar mines has been attributed to radon-daughter exposure (NCRP, 1984a). Both small-cell undifferentiated and epidermoid bronchogenic carcinomas have occurred at increased frequencies in these miners. Excessive rates of lung cancer due to radon-daughter exposure have led to ventilation standards for underground mines and greatly reduced radiation exposure to underground miners (NCRP, 1984a,b).

Health consequences of radon exposure to underground miners are the primary basis for determining health risk to people exposed to

pCi/l	WL	Comparable Exposure Levels	Comparable Risk *
200	1	1000 times average indoor level	More than 75 times non-smoker risk of dying from lung cancer
			4 pack-a-day smoker
100	0.5	100 times average indoor level	10,000 chest x-rays per year
40	0.2		30 times non-smoker risk of dying from lung cancer
20	0.1	100 times average outdoor level	2 pack-a-day smoker
10	0.05	10 times average indoor level	1 pack-a-day smoker
4	0.02		3 times non-smoker risk of dying from lung cancer
2	0.01	10 times average outdoor level	200 chest x-rays per year
1	0.005	Average indoor level	Non-smoker risk of dying from lung cancer
0.2	0.001	Average outdoor level	

* Based on lifetime exposure

Figure 3. Comparison of lung-cancer risk associated with radon exposure to risks associated with cigarette smoking and chest x-rays. A few houses have been found with levels over 100 pCi/l, and one house in Pennsylvania had a level over 2,000 pCi/l (Nero, 1986). Modified from EPA (1986).

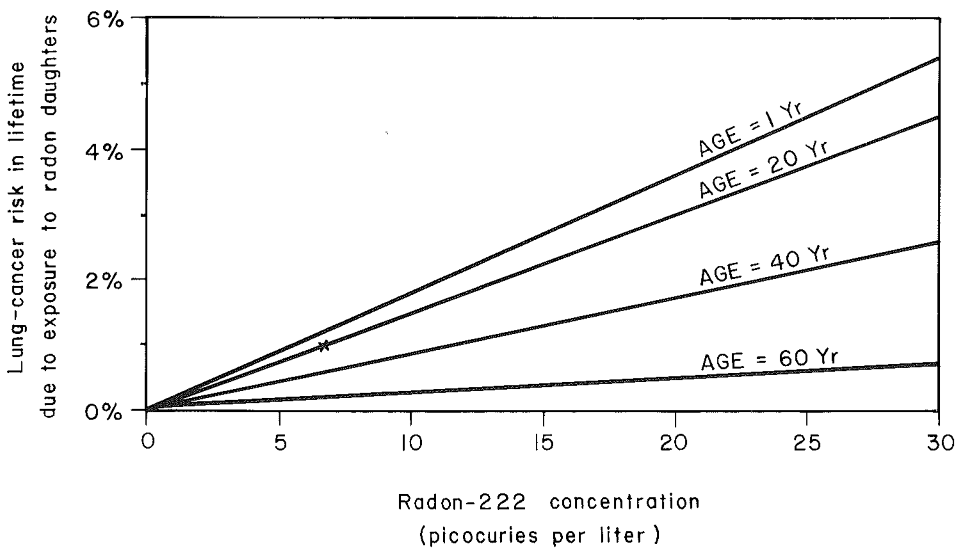

Figure 4. *Increase in lifetime lung-cancer risk associated with a range of indoor-radon concentrations, assuming that half of one's lifetime is spent indoors. Age corresponds to age of first exposure. Risk is calculated based on assumption of continuous exposure following first exposure. For example, if a 20-year-old moved into a house with 7 pCi/l radon ("x" in figure) and spent half of his time at home for the rest of his life, he would have a 1-percent chance of contracting lung cancer due to exposure to radon daughters. A 60-year-old who moved into the same house only increases his or her risk by about a 10th as much because an older person would be more likely to die of other causes before development of radon-related cancer due to exposure late in life. Based on Table 10.3 in NCRP (1984a).*

lower, more common radon levels in houses and other buildings. Unfortunately, there are many problems in determining excess cancer incidence as a function of total radon exposure for underground miners. Inaccuracy is due in part to inconsistent monitoring of radon levels in mines, especially before the mid-20th century when ventilation was poor and radon levels in mines were high, and to difficulty in keeping track of miners for tens of years after exposure.

Most estimates of lung-cancer risk due to low-level radon-daughter exposure in homes and buildings use a linear extrapolation from high exposure rates experienced by some groups of underground miners. In a linear extrapolation, exposure and risk are proportionally related; for example, half the exposure would constitute half the risk. There is limited evidence that linear extrapolation slightly overestimates risk at low-level radiation exposure (e.g., Cohen, 1983). The National Council on Radiation Protection and Measurements (NCRP) reviewed all available data on lung cancer and radon-daughter exposure from underground miners and laboratory animal studies. Based on a linear extrapolation from high exposure rates, the NCRP produced a table that allows estimation of risk, given number of years exposed to a particular level of radon daughters, duration of exposure, and age at first exposure (NCRP, 1984a; Figure 4). Their studies indicate that radon-related lung cancer rarely occurs before 5 to 7 years after exposure and that the period of time between exposure and cancer appearance decreases with age. Radon-related lung cancer rarely appears before age 40; the median age of appearance in miners is about 60 in nonsmokers and a few years younger in smokers.

Radon in Arizona

Based on national estimates of lung-cancer mortality due to radon-daughter inhalation, Arizona may have an unrecognized health hazard. This hazard, however, may not be as great as national estimates suggest because of several factors that are difficult to quantify. Common use of concrete-slab floors in Arizona homes tends to seal out soil gas and use of evaporative coolers elevates indoor air pressure, which keeps soil gas out. Because homes in southern Arizona are not heated as much as those in cooler areas of the country, they probably do not suck up as much soil gas. In addition, EPA estimates of radon-induced cancer are based on linear extrapolation from high exposure rates, which tends to overestimate cancer rates at lower, more common exposure rates.

In the more studied areas of the country, high indoor-radon levels have been found in structures built on uranium-rich bedrock and derivative soil, such as in an area of eastern Pennsylvania, northwestern New Jersey, and southeastern New York known as the Reading Prong. One home in eastern Pennsylvania had such high levels of radon that one of its occupants repeatedly set off radiation alarms at the nuclear power plant where he worked. Occupants of this home were receiving more than 100 times the maximum radon-related radiation exposure considered acceptable for underground uranium miners.

Arizona contains many uranium mineral districts and mines as well as other areas with higher-than-average uranium concentrations. Although the warm climate and common building-construction techniques may reduce movement of soil gas indoors, the common occurrence of uranium at elevated levels in geologic materials indicates a need for careful evaluation of the distribution and concentration of uranium and its relationship to indoor-radon levels. Because of the paucity of measurements for buildings in Arizona, knowledge of uranium concentrations in geologic materials is probably the most accurate basis for identifying the areas of the State that are likely to have high indoor-radon concentrations.

Average uranium concentration in granitic rocks is approximately 3 ppm, although values locally reach hundreds of parts per million. The Transition Zone in Arizona (Peirce, 1985) and some mountain ranges in the Basin and Range Province contain areas of 1.4-billion-year-old granite, which contain variable, but generally greater-than-average uranium concentrations. The two most uranium-rich granites known in Arizona are the Dells Granite near Prescott and the Lawler Peak Granite near Bagdad (Silver and others, 1980; Table 2; Figure 5). Granites of

Table 2. *Uranium content of typical basalt and granite and of several types of granitic rocks in Arizona, in parts per million (ppm).*

Rock Type	Average (ppm)	High Value (ppm)
Basalt (crustal average)	0.5-1	—
Granite (crustal average)	3.0	—
Wilderness granite, Santa Catalina Mountains (19 analyses from Reynolds and others, 1980)	1.17	2.9
Oracle Granite and gneissic derivatives, Santa Catalina Mountains (9 analyses from Reynolds and others, 1980)	3.5	8.1
Granitic rocks in Prescott 15′ quadrangle, including Dells Granite (13 analyses from May and others, 1982)	8.2	26.3
Lawler Peak Granite near Bagdad, Yavapai County (19 analyses total, highest 3 not included; from May and others, 1982)	14.6	51
Lawler Peak Granite, (highest 3 of 19 analyses included only; from May and others, 1982)	269	551

other ages in Arizona are not known to contain uranium at significantly elevated levels.

Numerous uranium deposits within the Colorado Plateau Province of Arizona occur primarily as breccia-pipe deposits in Paleozoic sedimentary rocks (Krewedl and Carisey, 1986) or as strata-bound deposits within Mesozoic sedimentary rocks (Peirce and others, 1970; Scarborough, 1981). Almost all of Arizona's uranium production has come from these deposits (Figure 5).

Oligocene and Miocene extensional faulting in the Basin and Range Province resulted in formation of numerous sedimentary basins. In some areas volcanic and sedimentary rocks deposited in these basins contain concentrations of uranium that range from slightly above normal to ore grade (Scarborough and Wilt, 1979; Figure 5). The Date Creek uranium district 60 km northwest of Wickenburg contains the largest known uranium deposit of this type. The Carefree-Cave Creek-New River-Lake Pleasant area north of Phoenix contains scattered outcrops of tilted Miocene sedimentary and volcanic rocks. Limestone, dolomite, cherty carbonate, and volcanic ash beds are interbedded with the sedimentary and volcanic rocks and are locally uranium rich (Scarborough and Wilt, 1979). Similar uraniferous carbonates are present in southwestern Tucson (Grimm, 1978; Keith and others, 1983). Uranium-rich rocks of this type probably underlie other basins within the Basin and Range Province in Arizona.

So few radon measurements have been made in Arizona buildings that it is difficult to assess the significance of the hazard to residents of the State. The detailed distribution of uranium concentrations in populated areas is poorly known, and it is unclear how well indoor-radon levels correlate with uranium concentrations in underlying soil and rock. Most houses and buildings in Arizona are built on soil and alluvial deposits, yet the soil-gas permeability and uranium concentration of soil and alluvium in Arizona are virtually unstudied.

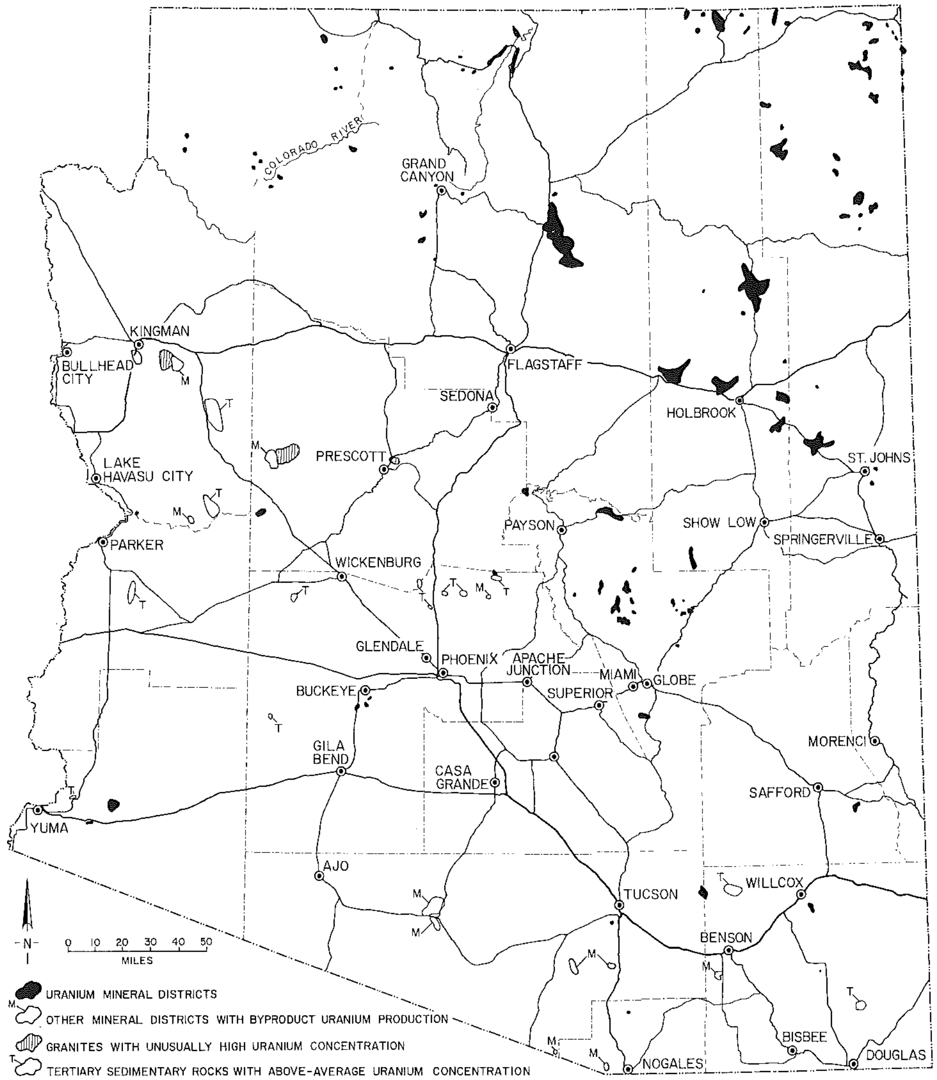

Figure 5. Areas in Arizona where anomalously high concentrations of uranium have been recognized. Simplified from Spencer and Shenk (in preparation).

Radon Detection and Reduction

Two types of radon monitors are commercially available for use in homes and other buildings. One type is the charcoal canister, a small can that is placed in the home, opened, and then closed after several days and returned to the manufacturer for analysis. Though excellent for a quick "spot check," this type of detector does not determine average radon levels over longer time periods. Seasonal radon-level variations, for example, could be substantial, and thus a quick spot check would not necessarily determine a radon level that represents the long-term average concentration. It is the best method, however, for quickly determining the approximate radon concentration in a home or building.

The other type of detector consists of a plastic film that records the tracks of alpha particles that are emitted by atmospheric radon and its decay products. The detector can be placed in the home for months or even a year, thus recording the long-term average radon concentration, which more accurately reflects health hazard. These detectors are more expensive ($30 to $50) than charcoal canisters ($15) and are not very accurate at determining low radon concentrations. As a result, they are most useful for follow-up measurements where a canister test has indicated concentrations above 4 pCi/l.

The most common method of reducing indoor-radon levels is to seal the floor so that soil gas can not easily enter the home. Other methods include ventilating the basement or crawl space, using fans to suck air from the basement or crawl space to the outside, and placing pipes under the home to remove soil gas before it reaches the home. Use of evaporative coolers and electrostatic dust filters also reduces radon-daughter levels. Methods of reducing indoor-radon levels are still being developed because radon has only recently been recognized as a geologic hazard.

Conclusion

High indoor-radon levels in residential buildings have only been recognized in the United States during the past 10 years, and the degree of risk associated with radon-daughter inhalation is only approximately known. The association of high indoor-radon levels with geologic materials containing unusually high uranium concentrations has been established in a general manner for the Reading Prong area in Pennsylvania, New Jersey, and New York. A recent study has outlined evidence that lung-cancer rates are higher than expected for people living in the Reading Prong area (Fleischer, 1986). Given this new knowledge and the presence of significantly greater-than-average uranium concentrations in parts of Arizona, research is clearly needed to locate inhabited areas built on "uranium-rich" geologic materials and to determine indoor-radon levels in these areas. Such research, combined with studies of yet uninhabited areas in regions of population growth, could prevent future problems associated with radon gas.

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FOR MORE INFORMATION ON RADON

An organization in each State has been designated by the U.S. Environmental Protection Agency to receive updated information on radon gas such as guidelines for maximum acceptable indoor-radon concentrations, information on commercial vendors of radon monitors, and methods for lowering radon concentrations in homes. In Arizona, this type of information can be obtained from the Arizona Radiation Regulatory Agency, 4814 S. 40th St., Phoenix, AZ 85040; tel. (602) 255-4845.

NEW ADDRESS

The Oil and Gas Conservation Commission has moved to a new location: Suite 190, 3110 N. 19th Ave., Phoenix, AZ 85015. The telephone number, however, has remained the same: (602) 255-5161. The commission promotes and regulates the production of oil, natural gas, helium, and geothermal resources within Arizona.

New Bureau Publications

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

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5.01 to 10.00, add 2.25	50.01 to 100.00, add 10.00
10.01 to 20.00, add 4.25	More than 100.00, add 10%
20.01 to 30.00, add 5.50	Foreign mail, add 40%
30.01 to 40.00, add 6.25	

Capps, R. C., Reynolds, S. J., Kortemeier, C. P., and Scott, E. A., 1986, Geologic map of the northeastern Hieroglyphic Mountains, central Arizona: Open-File Report 86-10, 16 p., scale 1:24,000; text: $2.75; map: $2.25.

The oldest rocks in the Hieroglyphic Mountains are Proterozoic schist, gneiss, metasedimentary and metavolcanic rocks, and several generations of plutonic rocks. These rocks are intruded by a small Late Cretaceous(?) granite and numerous middle Tertiary felsic to mafic dikes.

The crystalline rocks are depositionally overlain by a thin sequence of middle Tertiary clastic rocks and a thicker sequence of Miocene volcanic rocks. The volcanic rocks consist of basalt and andesite flows, latite and rhyolite flows and tuffs, and lesser amounts of volcaniclastic rocks. Overlying the volcanic rocks are coarse fanglomerate and landslide-related megabreccia that grade upward into sandstone and siltstone.

Low- to high-angle normal faulting and rotation of fault blocks occurred soon after the extrusion of the youngest volcanics and during deposition of the fanglomerate. Argillic and silicic alteration locally occurs in both Tertiary and pre-Tertiary rocks and is most intense in the Cedar basin area. Precious- and base-metal mineralization also occurs in the crystalline basement and in overlying Tertiary volcanic rocks.

Schnabel, Lorraine, and Welty, J. W., 1986, Bibliography for metallic mineral districts in La Paz, Mohave, and Yuma Counties, Arizona: Circular 25, 45 p.; $5.00.

This circular provides references for each known metallic mineral district in La Paz, Mohave, and Yuma Counties in Arizona. It is the second in a series of county-by-county bibliographies. Nearly 900 citations are included. Mineral districts are listed alphabetically; those with no reported production are included as well.

Schnabel, Lorraine, Welty, J. W., Trapp, R. A., and Reynolds, S. J., 1986, Bibliography for metallic mineral districts in Pima and Santa Cruz Counties, Arizona: Circular 26, 44 p.; $6.00.

In this third in a series of county-by-county bibliographies, references are provided for each known metallic mineral district in Pima and Santa Cruz Counties in Arizona. Nearly 1,100 citations are included.

Arizona Earthquake Information Center 1986 Activity Summary

by David S. Brumbaugh
Director

The Arizona Earthquake Information Center (AEIC) commenced operations in late November 1985. Most of the time between November 1985 and July 1, 1986 was spent in gearing up the center. This included moving into the headquarters on the Northern Arizona University (NAU) campus in Flagstaff, installing a computer, cataloging archives, and installing and testing remote field stations at Williams (WMZ) and the Grand Canyon (GCN).

The AEIC collects information from a network of four stations: Flagstaff (FLAG), Sunset Crater (SCN), Williams, and the Grand Canyon (Figure 1). This network enables detection of microearthquakes in northern Arizona (earthquakes of less than 3.0 magnitude on the Richter scale). It has been relatively quiet in northern Arizona during 1986; by the end of August, no events of magnitude 3.0 or greater had occurred. The last event in Arizona that exceeded 3.0 magnitude happened on April 15, 1985 south of Window Rock. The new seismic network, however, is detecting a surprisingly large number of microearthquakes. Four such events were located in July 1986 alone (Table 1).

Three of the events listed in Table 1 were large microearthquakes with magnitudes of 2.6. The largest event on July 17 occurred in the Mogollon Rim area near Sunset Mountain. On July 21 the network recorded an earthquake of magnitude 2.1 near the Oak Creek fault along the West Fork of Oak Creek Canyon. The other two events detected during July took place in the Defiance uplift area of northeastern Arizona on the southern Colorado Plateau. The event of July 31 is of particular interest because of its estimated depth of 38 kilometers. This would place it near the base of the earth's crust under the plateau. For a long time it was believed that earthquakes occurring in continental areas originated no deeper than about 15 kilometers. This was thought to occur because temperatures increase with depth below the Earth's surface. At a depth of 15 kilometers, temperatures would be high enough to make brittle faulting associated with earthquakes a seeming impossibility. More recent data from earthquakes under the plateau, however, seem to indicate otherwise. Two plateau earthquakes near Crown Point, New Mexico had depths between 40 and 60 kilometers (Wong and others, 1984). Although these deeper events are not yet fully understood, their occurrence is exciting to researchers in plateau seismology and will undoubtedly lead to new research programs.

Figure 1 shows that the only coverage of earthquake activity by stations in Arizona is provided by Tucson (TUC), Yuma (YMD), and the northern Arizona network. Large areas of the State have no stations that are close enough to detect and locate microearthquake events. Despite the need to expand station coverage, funds have been difficult to obtain. If funds are allocated, four stations in northern Arizona and two in central Arizona will be added. This would allow minimum coverage of microearthquakes in the more active parts of the State.

During 1986 the AEIC has sought funds to support the center's operating budget, salaries, and research. Research proposals were submitted to the U.S. Geological Survey Earthquake Hazards Reduction Program and the National Science Foundation. Although one proposal is still pending, results have been discouraging because of Federal cutbacks. Efforts have also been made to contact donors in the private and corporate sector. NAU provides partial support for operations and for salaries of graduate and undergraduate students working at the center. These funds must be increased, however, by $6,000 to $7,000, to ensure continuous operation of the center and its services to the public.

Table 1. Arizona earthquakes detected during July 1986.

Date	Latitude	Longitude	Depth (km)	Origin Time	Magnitude	Epicenter
7/17	34.935	111.021	0.1	21:13:48	2.6	Sunset Mountain
7/21	35.055	111.875	2.62	01:09:09.1	2.1	West Fork, Oak Creek
7/29	36.674	109.563	20.0	17:42:30.4	2.6	Ganado
7/31	36.28	109.661	38.3	20:37:23	2.6	Many Farms

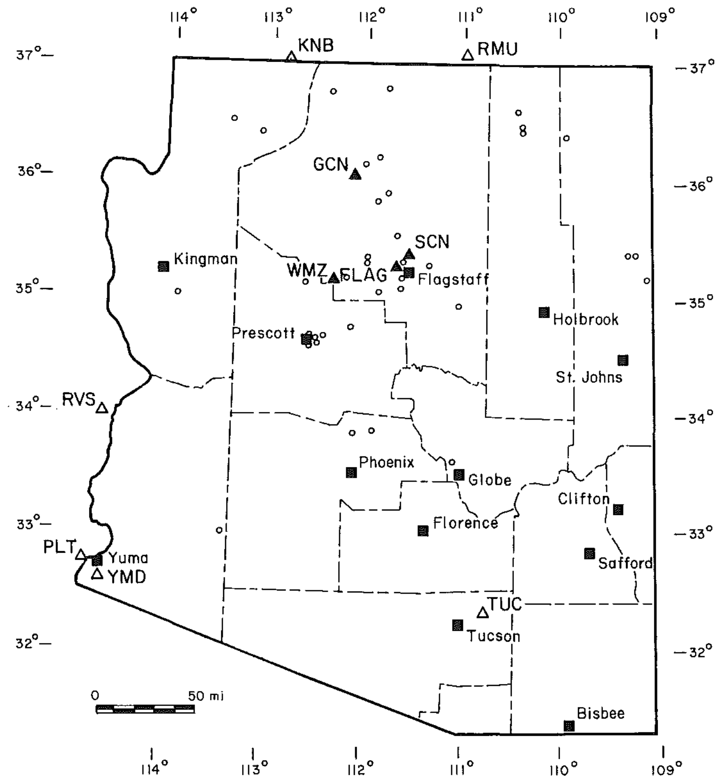

Figure 1. Epicenters of all Arizona earthquakes detected and located from 1971 through 1986 (open circles). Also shown are seismograph stations of the northern Arizona seismic network (solid triangles) and stations operated by other agencies (open triangles).

An important function of the AEIC is to inform Arizona residents about earthquakes in the State and, to a lesser extent, in nearby regions. Last summer AEIC personnel answered numerous inquiries from residents in Yuma and Phoenix on the series of moderate earthquakes (magnitude 5.0 to 6.0) that had occurred in southern California. The AEIC also established and strengthened contacts with government agencies involved with earthquake emergency planning such as the U.S. Bureau of Reclamation, Arizona Division of Emergency Services, and Office of Hazard Studies at Arizona State University in Tempe.

Another public service that AEIC personnel provide is guiding tours through the center. During the first 10 months of operation, 130 persons visited its facilities. This number is expected to rise sharply in 1987 as the AEIC advertises its services and holds open house.

The AEIC publishes a brochure titled "Arizona Earthquakes," which is available for 50¢. To obtain a brochure or arrange a tour of the center, contact the Arizona Earthquake Information Center, Box 5620, Northern Arizona University, Flagstaff, AZ 86011; tel. (602) 523-7197.

Reference

Wong, I. G., Cash, Dan, and Jacksha, Larry, 1984, The Crown Point, New Mexico earthquakes of 1976 and 1977: Bulletin of the Seismological Society of America, v. 74, p. 2435-2449.

Stewart Mountain Dam: Current Geologic Investigations

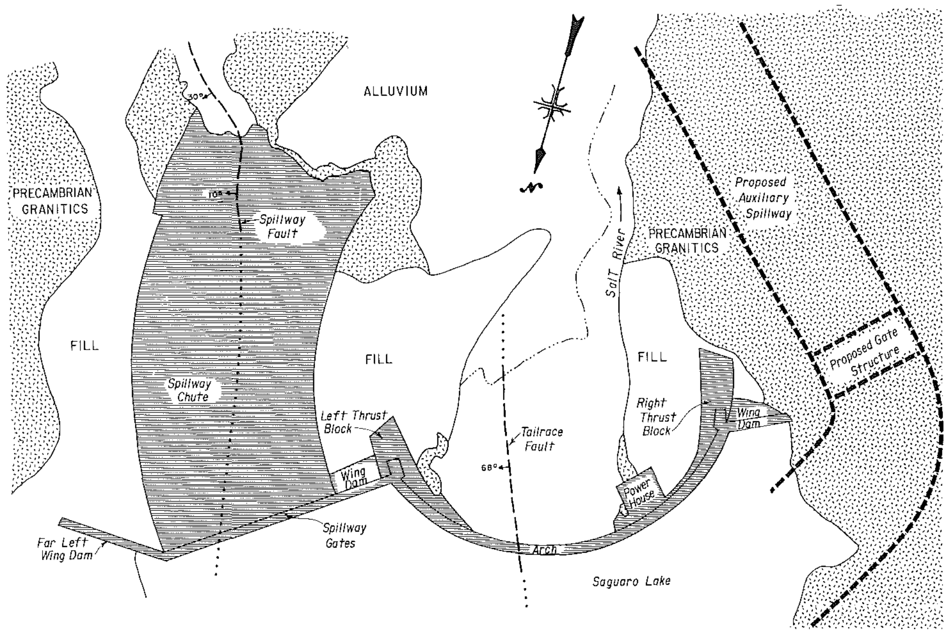

Figure 1. Stewart Mountain Dam, proposed auxiliary structures, and major geologic features. Because it is BOR convention to view damsites in the downstream direction, north points downward in this figure. A reverse view, with north pointing upward, is shown in Figure 2.

by Cathy S. Wellendorf

U.S. Bureau of Reclamation

Stewart Mountain Dam, located on the Salt River 40 miles northeast of Phoenix, was constructed by the Salt River Project (SRP) from 1928 to 1930. It is a multicurvature, thin-arch concrete dam with two gravity thrust blocks (Figure 1). The dam is about 200 feet high and has a crest length of 1,260 feet. It impounds Saguaro Lake with a current capacity of about 69,800 acre-feet.

The Bureau of Reclamation (BOR) is conducting geologic studies at Stewart Mountain Dam as part of a comprehensive project to correct one long-standing and two recently identified problems:

(1) Alkali-aggregate reaction. As a result of expansive reaction between cement and siliceous aggregate, the top of the arch has deflected approximately 6 inches upstream. When the dam was built, nothing was known about this reaction; evidence of the expansion was first reported in 1943. Little care was taken to analyze or select suitable aggregate. Aggregate was collected onsite from the channel of the Salt River. Unfortunately, those gravels included a high percentage of highly siliceous volcanic rock, which was later found to react with the cement. Those who are currently engaged in construction projects now realize the importance of careful selection of the aggregate source.

Stability analyses of the concrete and long-term survey monitoring of the arch indicate that the alkali-aggregate reaction and upstream deflection ceased in the mid-1960's. The potential for alkali-aggregate reaction in the future is considered very unlikely. Table 1 lists the alkali-reactive minerals and rocks.

(2) Seismic instability. A recent dynamic analysis indicates that the dam would be unable to withstand the maximum credible earthquake (MCE). The MCE is the most severe earthquake that appears capable of occurring on a potentially active fault under the presently known tectonic framework.

(3) Undersized spillway. Recent hydraulic studies indicate that the dam would overtop during the probable maximum flood (PMF) because of inadequate spillway capacity. The PMF is the estimated hypothetical flood volume and discharge that are considered to be the most severe, yet reasonably possible at the site.

To correct these potentially unsafe conditions, the BOR has proposed the following modifications:

(1) Rehabilitate and strengthen the arch. These improvements will involve the installation of post-tensioned tendons through the arch, addition of concrete on the downstream side of the thrust blocks, and drainage of the abutments and foundation.

(2) Build an auxiliary spillway. A right-abutment auxiliary spillway will increase the total spillway capacity from 120,000 cubic-feet-per-second (cfs) to 210,000 cfs, as required by the PMF, and will prevent overtopping.

SITE GEOLOGY

Stewart Mountain Dam is built on Precambrian quartz diorite intruded by irregular dikes of granite. Tertiary volcanic rocks, including tuffs and flows, rest unconformably on the Precambrian granitic rocks to the north and south of the dam (Figure 2).

At the damsite, the course of the Salt River follows a major shear zone, which at one time cut a canyon 90 feet below the present river channel, as revealed by numerous drill holes. The shear zone is oriented N. 10°-30° W. and contains two prominent faults. These faults are identified at the site as the Tailrace Fault, dipping 68° NE., and the Spillway Fault, dipping 10°-30° NE. (Figure 1).

North- and east-trending, near-vertical continuous joints are very prominent at the site, as is a set of joints that runs subparallel

***Table 1.** Alkali-reactive minerals and rocks.*

	COMPOSITION
MINERALS	
Opal	$SiO_2 \cdot nH_2O$
Chalcedony	SiO_2
Tridymite	SiO_2
Cristobalite	SiO_2
Heulandite	$H_4CaAl_2(SiO_3)_6 \cdot 3H_2O$
SILICEOUS ROCKS	
Opaline cherts	Opal
Chalcedonic cherts	Chalcedony
Siliceous limestones	Chalcedony and opal
VOLCANIC ROCKS	
Obsidian, perlite, pumice	Acidic to intermediate volcanic glass
Rhyolites and rhyolite tuffs	
Latites and latite tuffs	
Dacites and dacite tuffs	
Andesites and andesite tuffs	
MISCELLANEOUS ROCKS	
Any rocks containing veinlets, inclusions, or detrital grains of the reactive substances listed above.	

to the Tailrace Fault. Shallow-dipping joint sets are prominent but discontinuous.

ENGINEERING GEOLOGY

Foundation Conditions

No detailed geologic studies of the foundation were made before or during construction. The SRP archives, however, contain numerous photographs taken during construction of the dam that are invaluable in assessing foundation conditions.

The BOR's geologic site investigations began in mid-1984 and ended in early 1986. The engineering characteristics of the dam and proposed spillway foundations were determined by 1:600-scale surface mapping, three surface joint surveys, and 62 boreholes ranging in depth from 35 to 240 feet. Rock quality deteriorates from right to left (looking downstream) across the damsite because of deformation near the Tailrace and Spillway Faults. To analyze foundation stability, the site was divided into areas with similar engineering characteristics.

The rock of the right abutment is slightly weathered to fresh, hard, and slightly fractured. Joints are generally spaced 1 to 3 feet apart.

Although the Tailrace Fault does not crop out at the surface, its location and orientation are known from borehole data. Because of the steep northeasterly dip of this fault, only a very small portion of the dam's arch rests on it. The BOR's recent foundation-stability analysis indicated that the Tailrace Fault has no adverse effect on the stability of the arch.

The rock of the left abutment is situated between the Tailrace and Spillway Faults (Figure 1) and is cut by numerous associated shears. The rock is moderately to slightly weathered, moderately hard, and moderately fractured. Joints are spaced 0.3 to 1 foot apart. To compensate for this relatively poor-quality foundation, rock tendons, grouting, and drainage will be used to stabilize the left thrust block.

The Spillway Fault has been observed and mapped since spillway releases exposed it in 1965. Concrete has been placed over the highly erodible sheared rock to protect it from further erosion during future spillway releases. Although the Spillway Fault has a shallow northeasterly dip, its occurrence under the spillway gate structure does not significantly influence dam stability because the depth of water behind the spillway is relatively shallow.

Proposed Spillway

The proposed right-abutment auxiliary spillway will be built on slightly weathered to fresh, very competent rock. Slightly weathered rock is found 30 to 40 feet below most of the proposed abutment. Anomalously deep weathering occurs near the proposed gate structure. Although topographically this area constitutes a ridge, drill-hole data show that intensely weathered rock extends 45 to 75 feet below the ground surface in both the spheroidally weathered diorite and the more blocky granite (Figure 3). Much of the weathered granitic rock, or grus, appears to have weathered in situ. Boulder rubble mantling the ridge protects it from physical weathering or erosion; chemical weathering most likely proceeds under this protective "umbrella" (Figure 4). The foundation of the proposed gate structure will be about 100 feet below the ground surface, and therefore, in slightly weathered to fresh rock.

The right-hand cutslope of the auxiliary spillway will be about 100 feet high. Cutslope stability will be controlled by both joint orientation and degree of weathering. Orien-

(continued on page 11)

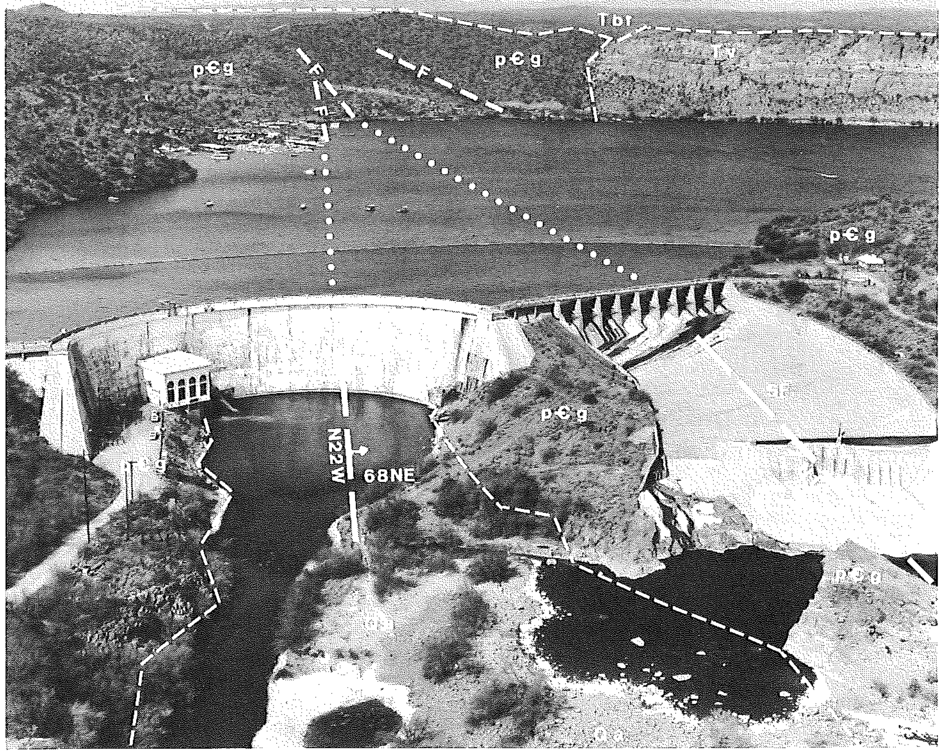

Figure 2. *Stewart Mountain Dam, looking north. Symbols refer to the regional geology: active terrace deposits (Qa); Tertiary basin-fill deposits (Tbf); Tertiary volcanic rocks (Tv); Precambrian granitic and metamorphic rocks (pCg); Spillway Fault (SF); Tailrace Fault (TF); and unnamed faults (F). Photo taken in September 1981 by J. Madrigal, U.S. Bureau of Reclamation.*

Figure 3. *Contact on right abutment of diorite (left) and granite (right). Note spheroidal weathering in diorite. Photo courtesy of the U.S. Bureau of Reclamation.*

Recent Publications on the Geology of Arizona

The following publications were recently added to the Bureau library, where they may be examined during regular working hours. Copies may also be obtained from the respective publishers.

U.S. Geological Survey

Maps

HA-687—Taylor, O. J., Hood, J. W., and Zimmerman, E. A., 1986, Hydrologic framework of the Upper Colorado River Basin—excluding the San Juan Basin—Colorado, Utah, Wyoming, and Arizona, scale 1:3,000,000.

MF-1183-A—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of lead in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-B—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of copper in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-D—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of zinc in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-G—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of tungsten in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-H—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of bismuth and beryllium in the nonmagnetic fraction of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-I—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of tin in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-J—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of manganese in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

MF-1183-K—Watts, K. C., Hassemer, J. R., Forn, C. L., and Siems, D. F., 1986, Geochemical maps showing distribution and abundance of barium in two fractions of stream-sediment concentrates, Silver City 1° x 2° quadrangle, New Mexico and Arizona, scale 1:250,000.

Open-File Reports

85-527—Peterson, J. A., Cox, D. P., and Gray, Floyd, 1985, Mineral-resource assessment of the Ajo and Lukeville 1° x 2° quadrangles, Arizona, 77 p., scale 1:250,000, 3 plates.

86-222—Tanner, A. B., 1986, Indoor radon and its sources in the ground, 5 p.

86-458A—Wenrich, K. J., Billingsley, G. H., and Huntoon, P. W., 1986, Breccia pipe and geologic map of the northeastern Hualapai Indian Reservation and vicinity, Arizona, 29 p., scale 1:48,000, 2 plates.

86-458B—Billingsley, G. H., Wenrich, K. J., and Huntoon, P. W., 1986, Breccia pipe and geologic map of the southeastern Hualapai Indian Reservation and vicinity, Arizona, 26 p., scale 1:48,000, 2 plates.

Other Publications

Arizona Department of Water Resources, 1986, Analysis of Butler Valley aquifer test: Open-File Report 1, 36 p.

Babcock, J. A., Cameron, J. A., and Heidenreich, L. K., 1986, Annual static-water-level basic-data report, Tucson basin and Avra Valley, Pima County, Arizona, 1985: Tucson Water Planning Division, 184 p., 4 plates.

Camp, P. D., 1986, Soil survey of Aquila-Carefree area, parts of Maricopa and Pinal Counties, Arizona: U.S. Soil Conservation Service, 306 p., 52 plates.

Carr, J. E., 1986, Sedimentary tectonics and the Cenozoic history of the Verde Valley near Camp Verde, Yavapai County, Arizona: Flagstaff, Northern Arizona University, M.S. Thesis, 197 p., scale 1:24,000, 2 plates.

Clark, L. D., and Verity, V. H., 1986, Laws and regulations governing mineral rights in Arizona, 9th ed.: Arizona Department of Mines and Mineral Resources, 91 p.

Condit, C. D., 1984, The geology of the western part of the Springerville volcanic field, east-central Arizona: Albuquerque, University of New Mexico, Ph.D. Dissertation, 453 p., scale 1:24,000, 2 plates.

Currier, D. A., 1985, Structures and microfabrics of a zone of superposed deformation, foothills fault zone, east flank of the Huachuca Mountains, southeast Arizona: Tucson, University of Arizona, M.S. Thesis, 167 p., 6 plates.

Faulds, J. E., 1986, Tertiary geologic history of the Salt River Canyon region, Gila County, Arizona: Tucson, University of Arizona, M.S. Thesis, 319 p., scale 1:24,000, 3 plates.

Kenny, Ray, 1986, Reconnaissance environmental geology of the Tonto foothills, Scottsdale, Arizona: Tempe, Arizona State University, M.S. Thesis, 158 p., scale 1:24,000, 4 plates.

Laubach, S. E., 1986, Polyphase deformation, thrust-induced strain and metamorphism, and Mesozoic stratigraphy of the Granite Wash Mountains, west-central Arizona: Urbana-Champaign, University of Illinois, Ph.D. Dissertation, 180 p.

McDonnell, J. R., Jr., 1986, Mineral investigation of a part of the Table Top Mountains Wilderness Study Area (AZ-020-172), Pinal and Maricopa Counties, Arizona: U.S. Bureau of Mines Mineral Land Assessment Report MLA 54-86, 14 p.

Maynard, S. R., 1986, Precambrian geology and mineralization of the southwestern part of the New River Mountains, Maricopa and Yavapai Counties, Arizona: Albuquerque, University of New Mexico, M.S. Thesis, 155 p., 3 plates.

Moore, R. B., 1974, Geology, petrology, and geochemistry of the eastern San Francisco volcanic field, Arizona: Albuquerque, University of New Mexico, Ph.D. Dissertation, 365 p., scale 1:50,000.

Moyer, T. C., 1986, The Pliocene Kaiser Spring (AZ) bimodal volcanic field; geology, geochemistry, and petrogenesis: Tempe, Arizona State University, Ph.D. Dissertation, 318 p.

Sullivan, C. E., 1978, Uranium and other trace-element geochemistry of the Hopi Buttes volcanic province, northeastern Arizona: Albuquerque, University of New Mexico, M.S. Thesis, 82 p.

U.S. Department of Agriculture, 1986, Draft environmental impact statement, proposed Mt. Graham astrophysical area, Pinaleno Mountains, Coronado National Forest: 217 p.

GEOLOGIC PLACE NAMES

Wickenburg, Maricopa County, Arizona. Population 4,134.

Heinrich Heintzel, or Henry Wickenburg (b. Austria 1820; d. 1905), fled from his native country because in all innocence he had sold coal from his father's property instead of turning it over to the state, and as a result, was being pursued by the police.

Wickenburg arrived in Arizona in 1862. Two years later he discovered the Vulture mine, but in the same year sold his interest to devote himself to ranching. He established his ranch near the site of the future town of Wickenburg.

Wickenburg was not a successful rancher. His place was in what in 1864 was called the Hassayampa Sink, a land of sand and rocks and too little water, where only four men lived at the time. As the Vulture mine developed, so did Wickenburg village as a supply point for the mine, and by 1870 there were 474 people in Wickenburg.

Whereas the town of Wickenburg prospered, the man himself did not. Discouraged and tired, Wickenburg shot himself in 1905, 51 [sic] years to the day after the first ore from the Vulture mine had been crushed.

Vulture mine, Maricopa County.

In 1863 [sic] Henry Wickenburg discovered the Vulture mine, one of the richest in Arizona's territorial history. There are various stories concerning how Wickenburg stumbled across the mine. One is that he shot a vulture and on picking it up noticed nuggets lying on the ground. A second says that his burro ran away and in anger Wickenburg threw rocks at it until he noticed that one of the rocks contained gold. Another reports that Wickenburg noticed a number of buzzards hovering over this peak at the time that he made his discovery.

During the Civil War, there was a great demand for gold and the Vulture mine helped supply the need. By the end of the war, there were 40 mills in operation at the mine, and another 4 were built on the Hassayampa in the ensuing year. Others were added later. Wickenburg sold the mine at an early date and so did not share in the vast wealth taken from it.

—Excerpted from Granger, B. H., 1960, Will C. Barnes' Arizona place names: Tucson, University of Arizona Press, p. 196-197.

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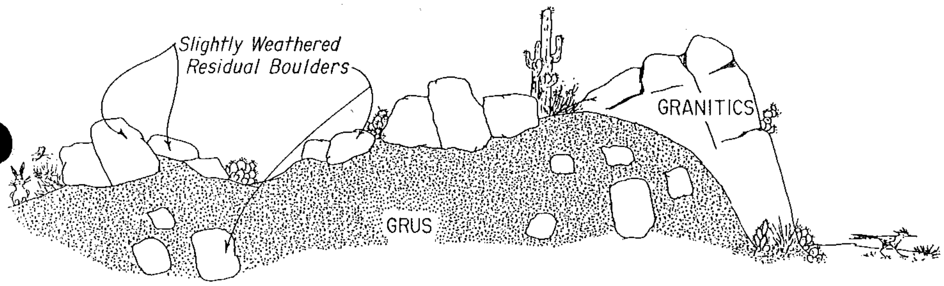

Figure 4. Weathering conditions at the proposed auxiliary spillway.

tations of prominent joint sets were determined using a borehole television camera equipped with a weighted compass.

Ground-Water Conditions

The potential head of about 110 feet created by Stewart Mountain Dam quickly dissipates under the dam because of the low permeability of the bed rock and, more importantly, the short travel path and ready escape of seepage to the tailrace that result in a very steep slope of the piezometric surface. Visible seepage below the dam is insignificant, only about 75 gallons per minute. Seepage obscured under manmade fill and downstream alluvium is also probably small.

Local artesian conditions were encountered in a few drill holes that intersected a single fracture or system of interconnected fractures that are open under the reservoir but confined farther downstream. There is no evidence to suggest that these few scattered artesian occurrences are interconnected or detrimental to dam stability.

Seismotectonic Investigations

Although the frequency of earthquakes in Arizona is very low, Stewart Mountain Dam could experience moderate to strong vibrations from a potential earthquake source: Sugarloaf Fault, a northwest-trending, down-to-the-northeast normal fault 9 miles north of the dam. Though merely 6 miles in length, this fault is the only structure within 22 miles of the dam that displays evidence of recurrent Quaternary activity. Based on scarp height, fault length, and comparison to other active and inactive faults in the Basin and Range Province, the MCE for the Sugarloaf Fault is estimated to be of magnitude 6.75. Because other potentially active faults are farther from the damsite, they would produce less severe effects.

The potential for surface faulting beneath Stewart Mountain Dam is considered extremely low. No data are available with which to positively date the Tailrace or Spillway Faults; however, geomorphic and geologic data indicate that the faults and shears within the Precambrian rocks of the dam foundation are very old features with no evidence of Quaternary activity. A detailed lineament analysis, local and regional structural relationships, and the age and distribution of Quaternary terrace deposits along the Salt River support this interpretation.

New Publications for the Layman

The Making of a Continent, 1986, by Ron Redfern, 242 p. A companion text to the recent six-part series on the Public Broadcasting Service, this volume investigates the geologic history of the North American continent—how the continent came to be and how life evolved upon it. Redfern integrates color photographs, illustrations, and narrative to explain the events that shaped the natural and human history of North America. Copies are available for $16.95 each from the American Geological Institute, 4220 King St., Alexandria, VA 22302.

Pages of Stone, Geology of Western National Parks and Monuments; v. 3, The Desert Southwest, 1986, by Halka Chronic, 168 p. In addition to describing the geology of several areas administered by the National Park Service, Chronic introduces the reader to basic geologic concepts. Terms are defined in the text and in a separate glossary. Areas within Arizona that are included in this volume are the Chiricahua, Montezuma Castle, Tuzigoot, Organ Pipe Cactus, Saguaro, and Tonto National Monuments. Copies are available from The Mountaineers, 306 Second Ave. West, Seattle, WA 98119.

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- ☐ Other (please list) ______________

Association of American State Geologists

Every State except Hawaii has an agency that functions as the State geological survey. Some are affiliated with universities, others are part of a State department of natural resources or comparable agency, and several are independent agencies that report to the governor. Regardless of their differences in organizational structure, State geological surveys are generally the primary State agencies for providing geologic information (maps, data, and reports of investigations) and services.

Those who administer a State geological survey either carry the title of or are informally referred to as "State geologist." In 1908 the State geologists formed an organization known as the Association of American State Geologists (AASG). Objectives of the AASG are to advance the science and practical application of geology, to provide a forum for learning from each other, to improve methods of assembling data and disseminating results, and to interact with Federal agencies and other groups whose missions relate to those of the State geological surveys.

The 78th annual meeting of the AASG was held in June in Long Beach, California, with Dr. James F. Davis, State Geologist of California, serving as host and Dr. Frank E. Kottlowski, State Geologist of New Mexico, as president. In addition to the regular business meetings, field trips were conducted that enabled participants to observe various local aspects of applied geology and mineral resources.

In 1986 the AASG published two items that may be of interest to some readers. The State Geologists' Journal (v. 38, 1986) includes a 2- to 3-page description of the major activities of each State geological survey during 1985. Copies may be purchased for $10.00 each. The List of Publications of the Association of American State Geologists (v. 2, 1986) can be purchased for $2.00 per copy. It includes items published by State geological surveys during 1985. Both publications can be obtained from Dr. Ernest A. Mancini, State Geologist, Geological Survey of Alabama, P.O. Box O, Tuscaloosa, AL 35486.

Officers of the AASG for 1986-87 are as follows: President, Charles W. Hendry, Jr. (Florida); President-Elect, Charles G. Groat (Louisiana); Vice President, Larry D. Fellows (Arizona); Secretary-Treasurer, Ernest A. Mancini (Alabama); Editor, Robert C. Milici (Virginia); Statistician, Morris W. Leighton (Illinois); and Historian, John H. Schilling (Nevada).

Additional information about the AASG or State geological surveys (addresses, telephone numbers, etc.) may be obtained by writing to Dr. Larry D. Fellows, State Geologist, Arizona Bureau of Geology and Mineral Technology, 845 N. Park Ave., Tucson, AZ 85719.

Meetings and Special Events

Tucson Gem & Mineral Show. Annual exhibit, February 12-15, 1987, Tucson, Ariz. Contact Tucson Gem & Mineral Show Committee, P.O. Box 42543, Tucson, AZ 85733.

Geoscience Daze. Annual student colloquium, April 1-2, 1987, Tucson, Ariz. Contact Bill McClelland, Dept. of Geosciences, 560-B Gould-Simpson Bldg., Univ. of Arizona, Tucson, AZ 85721.

Arizona-Nevada Academy of Science. Annual meeting, April 18, 1987, Flagstaff, Ariz. Contact Dale Nations, Box 6030, Geology Dept., Northern Arizona Univ., Flagstaff, AZ 86011.

Fieldnotes

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State of Arizona .... Governor Bruce Babbitt
University of Arizona .... President Henry Koffler
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State Geologist & Assistant Director,
Geological Survey Branch .... Larry D. Fellows
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