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Geology of the Vulture Gold Mine

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The Vulture mine in the Vulture Mountains of west-central Arizona is one of Arizona's largest historic gold mines. The mine yielded approximately 340,000 ounces of gold and 260,000 ounces of silver from 1863 to 1942 (White, 1988).

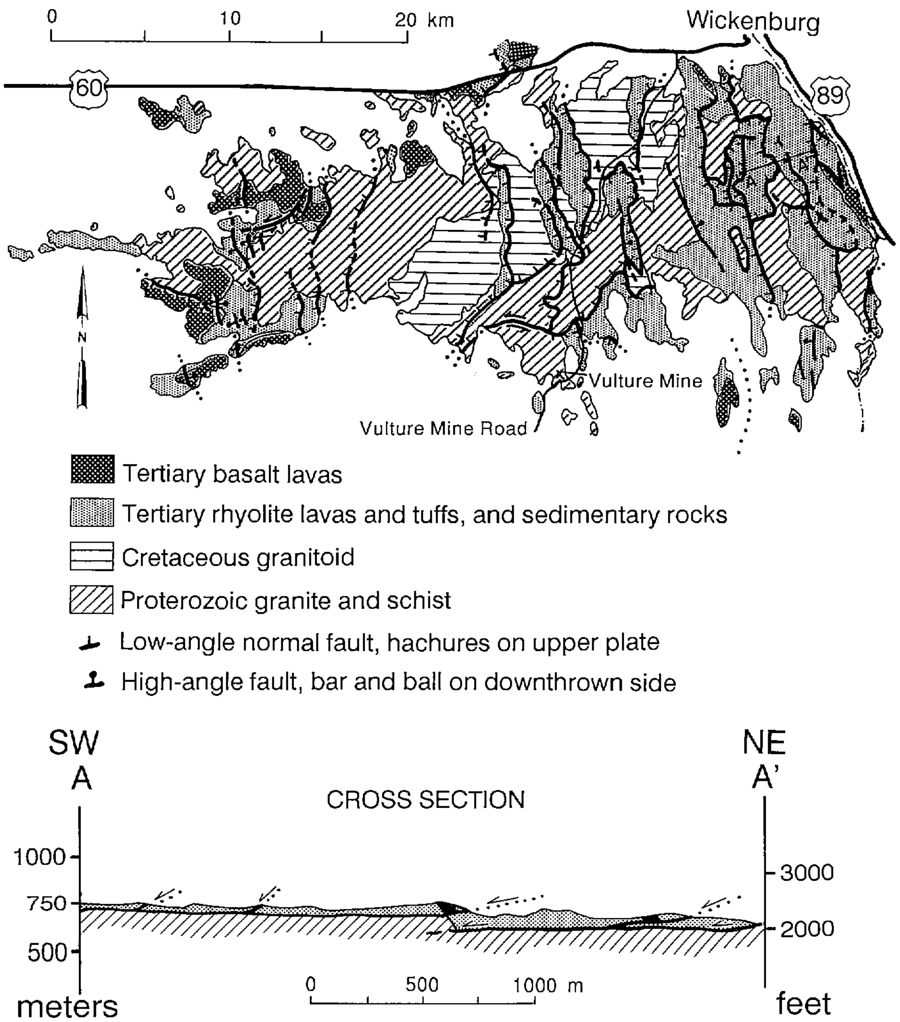


Figure 1. Simplified geologic map and cross section of the Vulture Mountains (from Grubensky and others, 1987; Grubensky and Reynolds, 1988; and M.J. Grubensky, unpublished mapping).

The approximately 1 million tons of ore mined had an average grade of 0.35 ounces per ton of gold and 0.25 ounces per ton of silver. In spite of significant gold production, the deposit has received little geologic study until recently (Reynolds and others, 1988; White, 1988). Recent geologic mapping and laboratory studies by the authors of this article, drilling, and deposit evaluations have led to a much better understanding of the geologic characteristics, age, origin, and evolution of the deposit.

New mapping in the Vulture Mountains was partially supported by the U.S. Geological Survey and Arizona Geological Survey Cooperative Geologic Mapping (COGEOMAP) program. Results of these investigations have implications for exploration strategies in the Vulture mine area and in similar highly extended areas elsewhere in Arizona.

Geologic Setting

Rocks in the Vulture Mountains consist of a variety of Proterozoic metamorphic and igneous rocks, a Cretaceous granite or granodiorite pluton, and lower to middle Miocene volcanic and sedimentary rocks. Large-magnitude, middle Miocene extension, common to most of western Arizona, was accommodated in the Vulture Mountains by movement on numerous listric and planar normal faults. Normal faults and fault blocks were tilted to the east or northeast during extension. Miocene strata now typically dip steeply or are locally overturned to the east or northeast and faults dip gently to the west or southwest (Figure 1).

Geology of the Vulture Mine

Mineralization and alteration at the Vulture mine occurred primarily within and directly adjacent to a north-dipping quartz porphyry dike that extends eastward from a Late Cretaceous pluton and intrudes Proterozoic crystalline rocks (Figures 2 and 3). Moderate to severe alteration of the dike and wall rocks has converted feldspar and mafic miner-

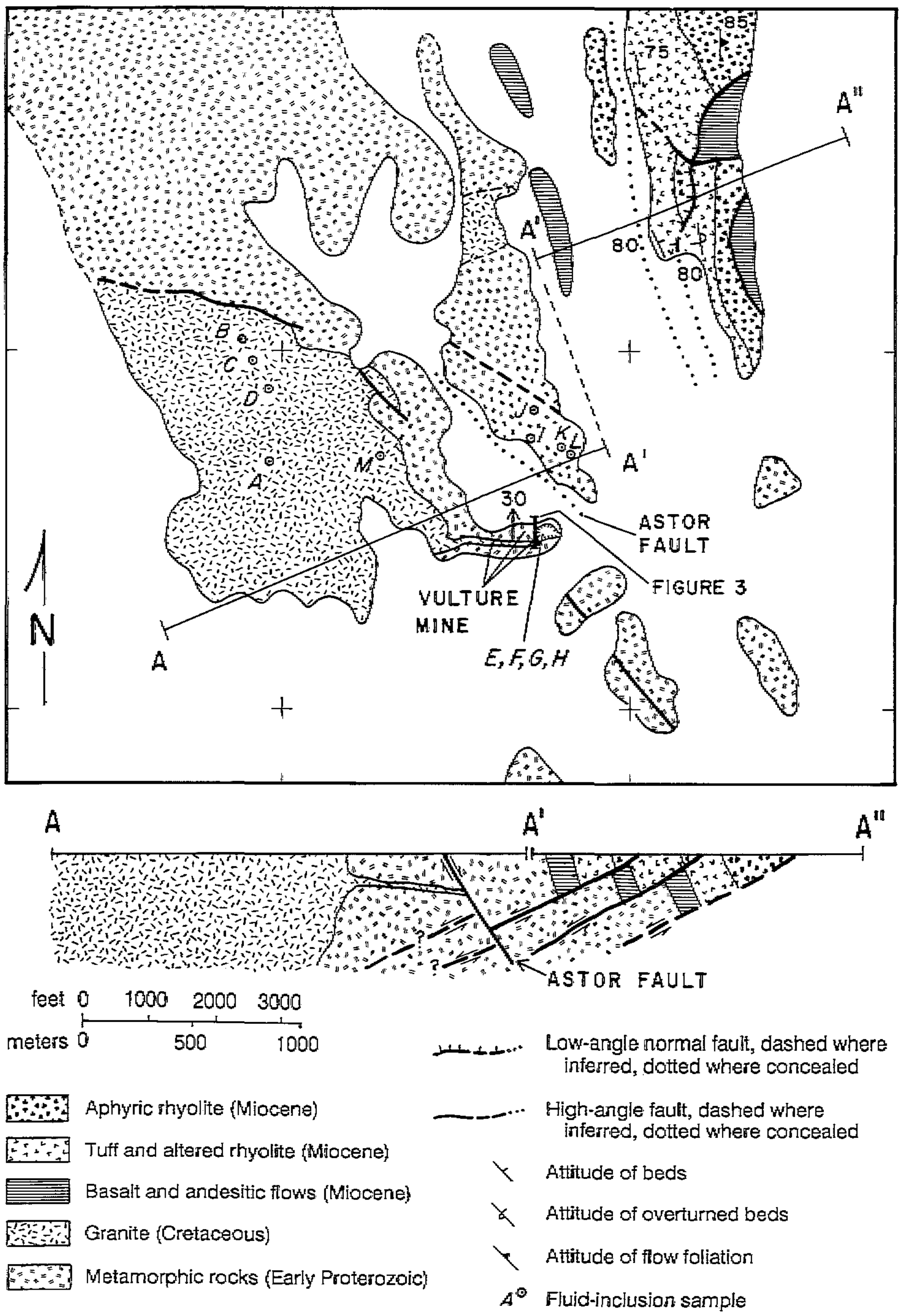


Figure 2. Simplified geologic map of the Vulture mine area and fluid-inclusion sample locations.

als to fine-grained sericite, hematite, and clay minerals. Altered dike rocks commonly consist of quartz "eyes" in a fine-grained matrix of alteration minerals. Gold is concentrated in quartz veins and in silicified and altered rocks within and adjacent to the dike (Figure 3). Gold is present as either native metal or electrum and is associated with pyrite, argentiferous galena, and minor amounts of chalcopyrite and sphalerite. There is a positive correlation among abundances of secondary silica, sulfides, and gold (White, 1988).

The Miocene volcanic rocks northeast of the Vulture mine were deposited on the Proterozoic crystalline rocks that host the Vulture mine gold deposit (Reynolds and others, 1988). The originally horizontal volcanic strata and their crystalline substrate have been rotated 70° to 90° so that bedding is now almost vertical. Rocks exposed in the Vulture mine area, therefore, represent an originally vertical cross section that has been tilted approximately 80° to the east by rotational normal faulting. The map view (Figure 2) represents what was originally a vertical cross-section view; what is visible in a north-south cross section (Figure 3) was originally horizontal.

Conceptual restoration of the rocks of the Vulture mine area to their prerotation orientation reveals the approximate geometry of the ore deposit at the time of mineralization. Mineralization and alteration originally occurred along a north-northeast-trending subvertical dike that projected upward from the structural top of a Cretaceous granitoid pluton (Figure 4A). The association of gold with the dike (Figure 3) and gradation of the dike into the granitic rocks of the pluton indicate that gold mineralization was intimately related to Cretaceous magmatism and dike emplacement. Later erosion and subsequent burial by lower Miocene volcanic rocks (Figure 4B) was followed by structural dismemberment and tilting (Figure 4C) and eventual uncovering by late Cenozoic erosion. The Astor fault (Figure 3), which is probably one of the youngest faults in the area, cuts the deposit and has displaced its down-dip continuation by an unknown amount (White, 1988).

Fluid-Inclusion Characteristics

Fluid inclusions are bubbles of liquid and gas that are trapped inside minerals during mineral formation. The composition of fluids in inclusions that were trapped in mineral deposits at the time of deposit formation reflects the composition of the aqueous fluids from which the deposits formed. One can determine the salinity of the inclusions by measuring the freezing temperature of the trapped fluid. The minimum temperature of the fluid at the time it was trapped can be determined by heating the sample until the two phases (liquid and gas) in the inclusion become one. (This is called the *homogenization temperature.*) Fluid inclusions that formed during precipitation of host minerals are called *primary,* whereas those that formed later along fracture planes are called *secondary.*

Quartz veins are numerous over a broad area around the Vulture mine. Samples of veins were collected from an area (Figure 2) that represents an originally vertical cross section through the Vulture mine and that includes more than 1 kilometer of paleodepth range. Homogenization temperatures of primary and secondary fluid inclusions vary from approximately 200°C to 320°C and calculated salinities vary from approximately 1 to 18 percent NaCl equivalent by weight. Homogenization temperatures and salinities generally decrease with decreasing paleodepth (Figure 5). These fluid-inclusion data reveal the temperatures and salinities of the hydrothermal fluids that were probably undergoing convective circulation above the Cretaceous intrusion and that were respon-

OF 88-10 Geologic map of the Vulture Mine Area
May 1988. 1:24,000 8 1/2 x 11 map. ± 6 sections

sible for much or all of the mineralization and alteration at the Vulture mine. Greater fluid temperatures at greater depths probably reflect heat from the magma intrusion (now the granitoid pluton) that lay beneath the Vulture mine deposit. Downward-increasing fluid salinities may reflect a downward increase in the proportion of aqueous fluid expelled by the magma during crystallization.

Conclusion

Recent geologic mapping of the Vulture Mountains and adjacent ranges has established that the area has undergone large-magnitude extension as a result of rotational normal faulting (Grubensky and others, 1987; Stimac and others, 1987; Grubensky and Reynolds, 1988; see also Rehrig and others, 1980). Geologic mapping in the Vulture mine area indicates that this area has been faulted and tilted like most of the range and that the Vulture mine gold deposit has been tilted approximately 80° (Reynolds and others, 1988). Drill-hole assay data show that mineralization is associated with a dike that extends from the structural top of a Cretaceous pluton (White, 1988). Fluid-inclusion studies indicate that mineralization at the Vulture mine deposit occurred within a larger system of circulating aqueous fluids in which temperature and salinity increased downward toward a crystallizing magma body.

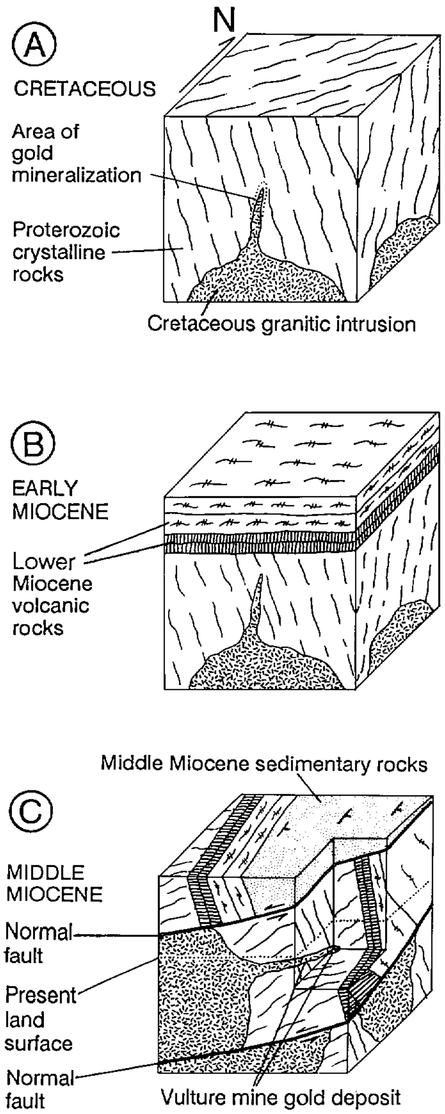


Figure 4 (left). Evolutionary block diagram of the Vulture mine area. Although only one generation of normal faults is shown, rotation probably occurred by movement on two or more generations of normal faults and is more complex than is shown here.

Figure 5 (below). Paleodepth versus salinity (upper diagram) and homogenization temperature (lower diagram) for fluid inclusions from quartz veins in the Vulture mine area. Paleodepth is the distance perpendicular to the approximately vertical disconformity at the base of Miocene volcanic rocks in the Vulture mine fault block. The actual depth of Vulture mine rocks at the time of mineralization was probably 1 to several kilometers.

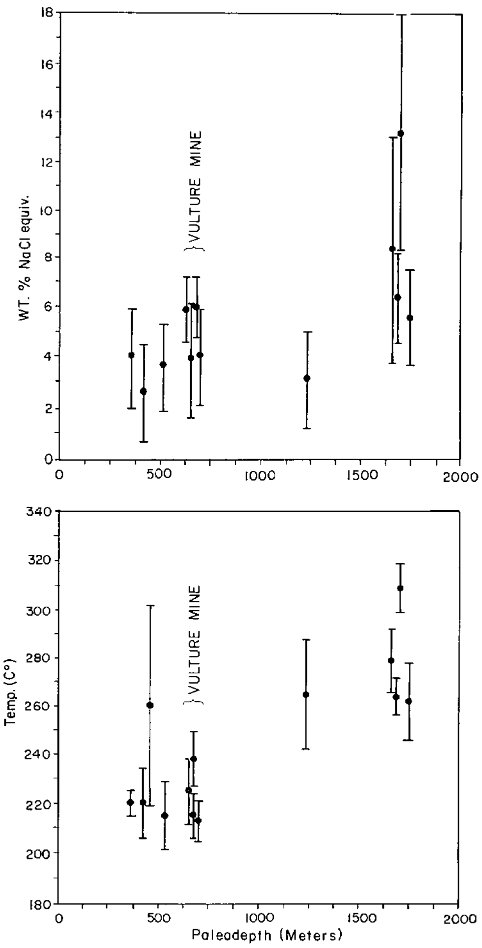
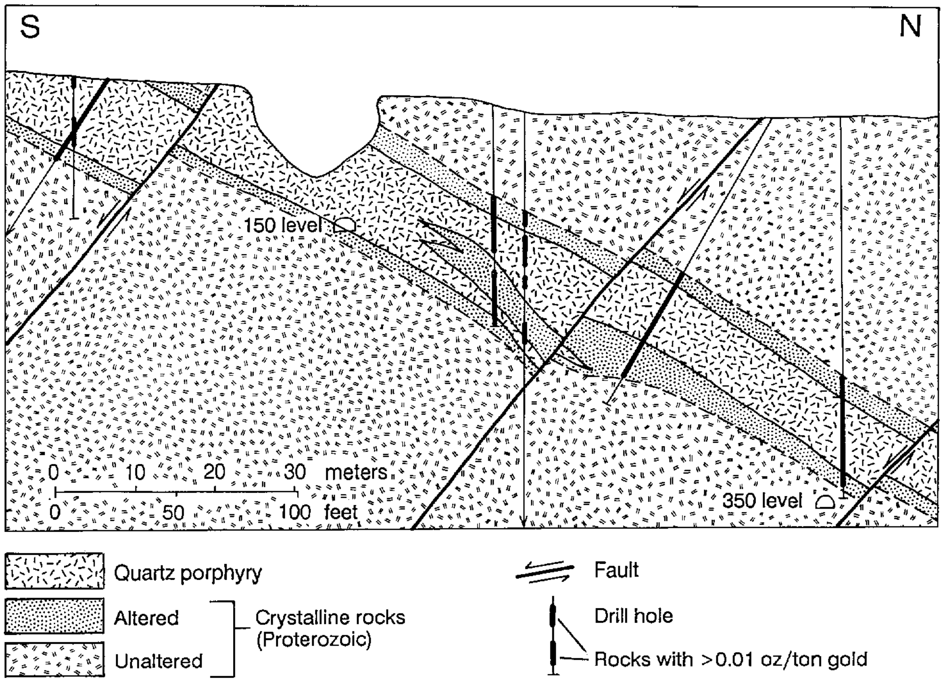


Figure 3 (below). Geologic cross section through the Vulture mine (modified from White, 1988 and unpublished data). See Figure 2 for location.



Recognition of this type of ore-deposit tilting and possible structural dismemberment has implications for exploration strategies in extended areas. Specifically, mineral exploration in highly extended areas characterized by rotational normal faulting may be facilitated by the knowledge that mineral deposits may have been tilted 80° from their original orientation. Such rotation provides a natural laboratory for the study of mineral deposits because the deposits are exposed in what was originally a near-vertical cross section. This type of extensional faulting may also cut an ore deposit into two or more pieces and leave them in shinglelike imbricate fault blocks separated from each other by several kilometers (e.g., Lowell, 1968).

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State Geological Survey - U.S. Geological Survey Meeting Held in Tucson

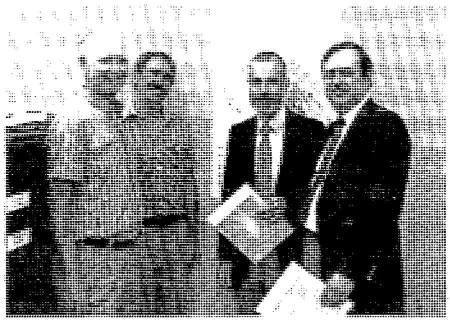


Figure 1. Representatives from the AZGS and USGS discuss the Cooperative Geologic Mapping (COGEOMAP) program. Left to right: Larry Fellows (AZGS Director and State Geologist), Steve Reynolds (AZGS Research Geologist), Ben Morgan (USGS Chief Geologist, Reston), and Dave Russ (USGS Assistant Chief Geologist for Programs, Reston).

The annual meeting of the directors of western State geological surveys and key U.S. Geological Survey (USGS) staff was held in Tucson October 22-25 at the Ghost Ranch Lodge. The purposes of the meeting were to improve communication between staff of the State and Federal surveys; learn about current activities, projects, and concerns (Figure 1); and explore ways of fulfilling the respective statutory mandates more effectively through improved coordination and cooperation. Ten of the 13 western State geological surveys were represented; approximately 20 USGS staff members, primarily from the Office of Mineral Resources, were also present.

Western State geologists held an all-day business meeting at the Arizona Geological Survey (AZGS) on October 21 (Figure 2). USGS geologists held a variety of postmeeting functions at their Arizona Field Office.

Two major discussion sessions were held at the joint meeting: (1) the Mineral Resources Data System (MRDS), a computerized database maintained by the USGS, and (2) outreach activities in earth science education. A half-day field trip was taken to observe detachment-fault geology and the impacts of ground-water withdrawal, subsidence, and earth fissures in the Picacho basin (Figure 3).

The 1990 meeting will be cohosted by the USGS and Idaho Geological Survey in Moscow, Idaho.

Figure 3 (above). AZGS geologists Phil Pearthree and Steve Reynolds discuss areas of subsidence and earth fissures in the Picacho basin with field-trip participants.

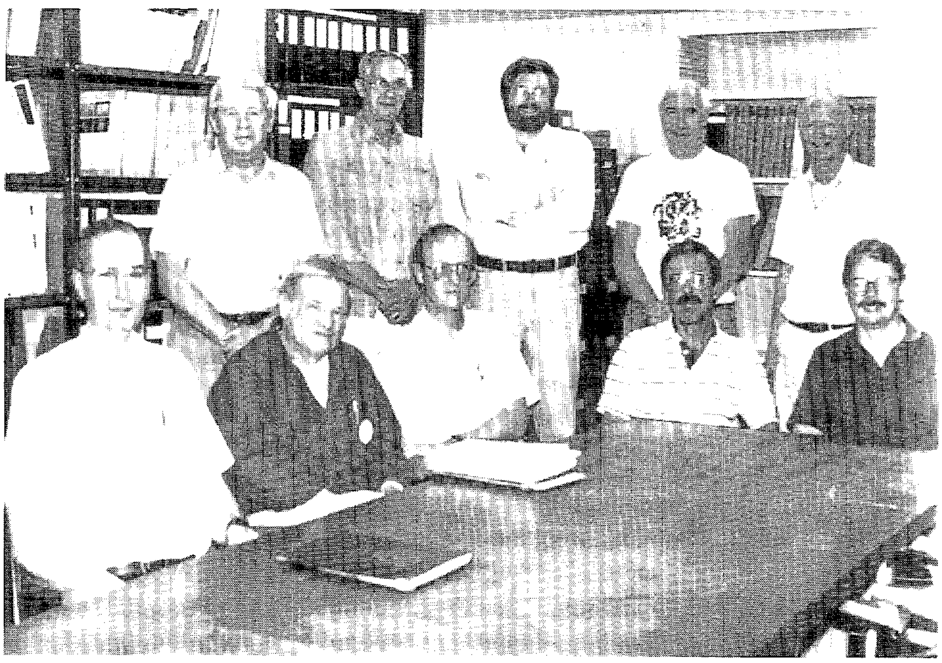


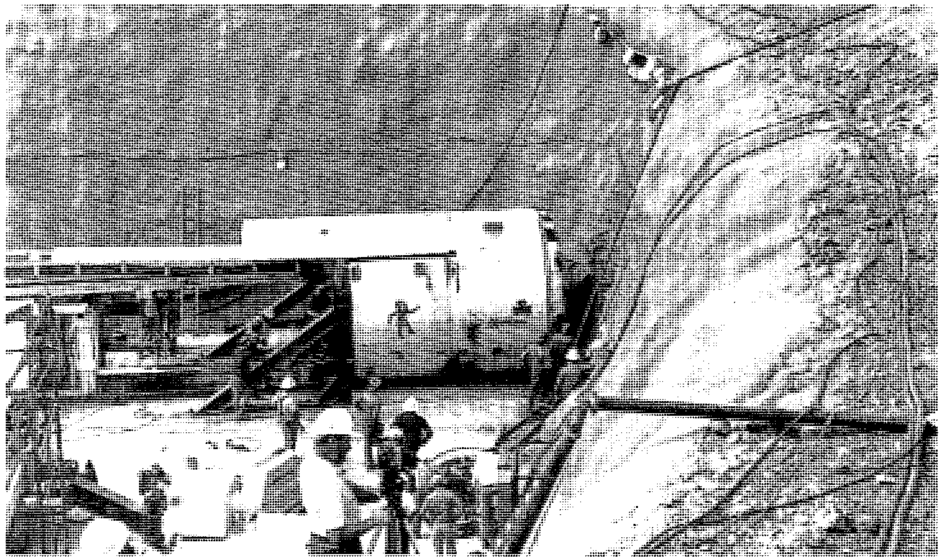
Figure 2 (left). Western State geologists meet to discuss mutual concerns. Top row, left to right: Bob Forbes (Alaska), Ed Ruppel (Montana), Jon Price (Nevada), Don Haney (Kentucky; President of the Association of American State Geologists), and Larry Fellows (Arizona). Seated, left to right: Eric Schuster (Deputy Director, Washington), Jim Davis (California), Earl Bennett (Idaho), Jamie Robertson (Deputy Director, New Mexico), and Lee Allison (Utah).

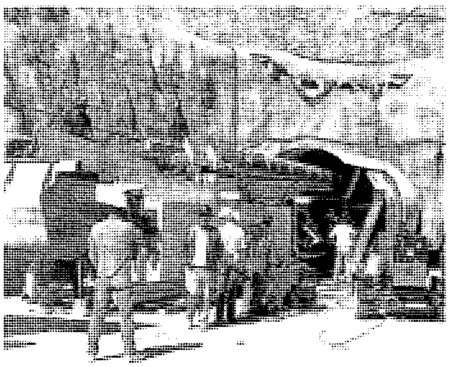
The Tucson CAP Tunnel: A Lesson in Engineering Geology

by Brad Herbert
U.S. Bureau of Reclamation

In 1973 construction began on the Central Arizona Project (CAP) at Lake Havasu on the western Arizona border. Today, 16 years later and nearly 330 miles farther, the continuous ribbon of canals, pipelines, tunnels, and pumping plants is at Tucson's doorstep, with completion scheduled for 1991. The last leg of the project bringing potable water to Tucson is now under construction. This final phase involves the excavation of an 8,340-foot-long, 12-foot-diameter tunnel through the southern Tucson Mountains. The tunnel will convey treated water from Tucson Water's treatment plant on the west side of the mountains to the utility's distribution system on the east.

National Projects Inc. (NPI) from Boise, Idaho constructed the $12.6-million tunnel under contract with the U.S. Bureau of Reclamation (BOR). NPI excavated and supported the tunnel, which was completed on October 25, and is now constructing an 8-foot-inside-diameter pipeline within the excavation to carry the water under pressure to the outlet, just west of Star Pass Golf Course.





Figures 1a and 1b (above and left). The TBM began its assault on the Tucson Mountains on March 17 as it ground into the shotcrete-covered rock surface at the inlet portal. The cylindrical TBM contains the cutter head, operating controls, motors, and hydraulic systems. It drags behind it an 80-foot-long trailing gear (the open rectangular structure), which contains electrical panels, air and water hoses, and the first portion of the muck (cuttings) conveyor system.

Conception and Siting

Originally, the treated water was to be pumped through a 5-mile-long buried pipeline that would run east along the Tucson-Ajo Highway to Robles Pass, where it would turn north and snake through the mountains to its terminus. When BOR geologists began investigations, however, they discovered problems with that location. A portion of the proposed pipeline traversed a steep colluvial slope. Water from a large wash had already eroded the toe of this slope and caused it to fail in one area. Constructing the pipeline across this slope would have been extremely difficult and assuring its stability would have been costly.

Another design problem uncovered during geologic investigations occurred where the pipeline was to pass through a small saddle within the Shorts Ranch Andesite. The design called for a cut approximately 40 feet deep through this saddle. When an exploration core hole was drilled in this area, geologists discovered that the condition of the rock was much worse than they expected. Less than 60 percent of the core was recovered, and what was recovered displayed evidence of extensive shearing and fracturing. Constructing a safe and usable excavation would have necessitated removing a hilltop on the west side and extending the cut on the east side nearly 100 feet up the mountain.

After these problems came to light, BOR designers examined several other construction-related problems more carefully. They realized that a less costly, more efficient, and more environmentally sound alternative was required. In 1986 they discussed the idea of a combination pipeline/tunnel. Initial cost analyses indicated that the tunnel option was economically feasible and geologic investigations were begun.

After initial reconnaissance and review of pertinent literature, BOR geologists began detailed geologic mapping in the fall of 1986 at a scale of 1:4,800 (1 inch equals 400 feet). The results of that mapping helped the geologists pinpoint areas that posed possible problems for tunnel excavation and stability. They conducted further investigations in these areas, including drilling six core holes on or near the alignment: two at both the inlet and outlet portals where stability could be a problem and two along a large fault that crossed the proposed tunnel. The drill holes along the fault revealed a 30-foot-thick clay gouge zone at tunnel level. This knowledge enabled BOR designers to plan for alternative support and excavation methods in this area.

Geologic mapping also revealed the possible existence of another, previously unmapped fault, which is a southwestern extension of a fault that Kinnison (1958) mapped. This fault closely paralleled a portion of the proposed tunnel alignment, a situation that could have made excavation and support difficult. Near-surface seismic refraction and resistivity surveys were conducted to confirm the existence of the fault. Although the results of the seismic survey were inconclusive, the resistivity survey revealed the existence of conductive ground at the suspected fault, indicating the presence of clay or moisture. These

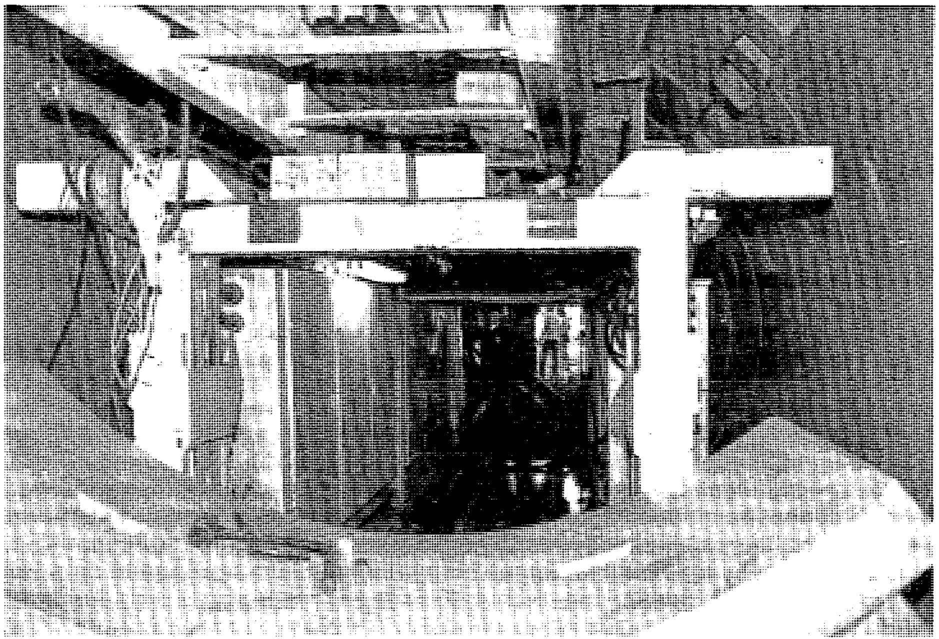


Figure 2. View from the rear of the TBM back through the trailing gear toward the inlet portal. The concrete segments in the foreground are ready to be set in place by the hydraulic erector arm (not pictured).

findings persuaded BOR designers to shift the alignment to the northwest to avoid the possible adverse effects of the fault.

BOR geologists analyzed and released the geologic data collected during the year-long study (U.S. Bureau of Reclamation, 1988). A copy of this report is available in the Arizona Geological Survey library.

Construction

Excavation of the tunnel proper began on March 17, 1989. NPI chose to advance the tunnel with a tunnel boring machine (TBM) rather than use a traditional drill-and-shoot (blast) method (Figures 1a and 1b). The TBM is designed with a slightly concave cutting head that turns up to 12 revolutions per minute and contains 24 separate roller cutters. Large "gripper" plates push against the sides of the tunnel to stabilize the machine while the cutting head is thrust forward at pressures of up to 4,000 pounds per square inch. Different types of cutters are typically needed for hard and soft rock. This TBM, however, was designed to run equally well with the same cutters in both rocks. This becomes advantageous when mixed faces are anticipated in a tunnel. A mixed face is encountered when two or more rock types are exposed at the face, or leading edge, of the tunnel. A TBM will generally deflect toward the softer rock, causing the tunnel to vary from proper line and grade. Mixed faces were expected in the Tucson tunnel throughout the megabreccia unit of the Cat Mountain Rhyolite sequence (Tucson Mountain Chaos). This TBM design was also advantageous when thick fault-gouge zones were encountered because the time-consuming process of changing cutters was eliminated.

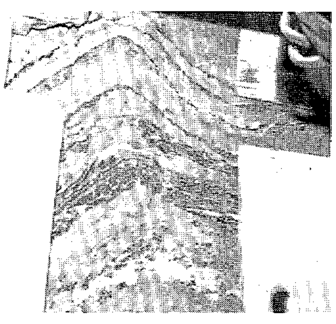


Figure 3. Folded sedimentary beds of the Cretaceous Amole Group seen between the concrete segments (left) and TBM shield (right). The top, or crown segment, is tightly secured in place with laminated wood blocks (upper left).

Precast concrete ring segments, rather than more traditional steel sets and rock bolts, supported the tunnel walls and crown. Each ring was composed of four individual segments. The segments were 5 inches thick and 4 feet wide and were installed directly behind the TBM with a specially designed hydraulic erector arm (Figure 2). This system provided immediate and continuous support in all rock types. Unfortunately, this system also covered up the rock as fast as it was exposed, making geologic mapping difficult at best.

As the excavation progressed, geologists prepared a descriptive log. On the TBM between the crown and side shields, a 4-inch "window" provided a view of the rock. From studying this window, geologists recorded the locations of significant geologic features. They also viewed the entire excavation for a short time just before a ring was constructed. Occasionally, they were allowed to examine the exposed cuts more thoroughly (Figure 3). Much of the exposed rock was completely covered with dust and mud; rock samples were, therefore, taken regularly for a detailed description of the lithology throughout the tunnel.

BOR geologists are compiling and analyzing all geologic data collected during tunneling for a final report. This report will include detailed descriptions of stratigraphy, structure, and lithologies in the tunnel, as well as how these parameters affected the excavation.

References

Kinnison, J.E., 1958, Geology and ore deposits of the southern section of the Amole mining district, Tucson Mountains, Pima County, Arizona: Tucson, University of Arizona, unpublished M.S. thesis, 126 p.

U.S. Bureau of Reclamation, Arizona Projects Office, 1988, Geologic design data report for Tucson tunnel, Central Arizona Project: 212 p., scale 1:600, 1:2,400, and 1:4,800, 5 sheets.

PROFESSIONAL MEETINGS

(1) Tucson Gem & Mineral Show. Annual exhibit, February 7-11, Tucson, Ariz. Contact Tucson Gem & Mineral Show Committee, P.O. Box 42543, Tucson, AZ 85733.

(2) Geosciences Symposium. Annual student colloquium, February 20-21, Tucson, Ariz. Contact Jay Jackson, Dept. of Geosciences, Gould-Simpson Bldg., University of Arizona, Tucson, AZ 85721; tel: (602) 621-6024.

(3) Cordilleran Section, Geological Society of America. Annual meeting, March 14-16, Tucson, Ariz. Contact Geological Society of America, 3300 Penrose Pl., Box 9140, Boulder, CO 80301; tel: (303) 447-2020.

(4) Geology and Ore Deposits of the Great Basin. Symposium, April 1-5, Reno, Nev. Contact Geological Society of Nevada, Box 12021, Reno, NV 89510; tel: (702) 786-0870.

(5) Arizona-Nevada Academy of Science. Annual meeting, April 21, Tempe, Ariz. Contact Edward Ricci, Director of Environmental Services, Water Resources Associates, Inc., 2702 N. 44th St., Suite 101B, Phoenix, AZ 85008; tel: (602) 381-1844.

The October 17, 1989 Loma Prieta (San Francisco) Earthquake

by Terry C. Wallace
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Arizona Geological Survey

At 5:04 p.m. on October 17, 1989, a magnitude 7.1 earthquake occurred along a section of the San Andreas fault in the Santa Cruz Mountains south of San Francisco. The earthquake, the largest to occur in the Bay area since 1906, caused more than $4 billion in damage and 66 deaths. During the 4 days that followed the earthquake, 19 aftershocks occurred with magnitudes larger than 4.0

The U.S. Geological Survey (USGS) designated this earthquake the *Loma Prieta* earthquake. Aftershocks indicated that a 40-kilometer(km)-long area on or near the San Andreas fault ruptured during the earthquake (Figure 1). The event was very unusual for several reasons. First, the focus was at a depth of 17 km. Most of the previous San Andreas earthquakes had foci shallower than 12 km. Second, faulting during the Loma Prieta earthquake was not purely strike-slip. Typical San Andreas earthquakes have been the result of horizontal slip on a vertical fault; the Pacific plate moved northwest relative to the North American plate (right-lateral strike-slip). The Loma Prieta event was a mixture of right-lateral strike-slip and thrusting motion, during which the Pacific plate moved up and over the North American plate (Figure 2). The fault plane dipped about 70° to the west. Third, very little surface faulting associated with this earthquake has been detected, even though the aftershocks nearly reached the surface. Typical strike-slip earthquakes of this magnitude have had surface displacements of 1 to 3 meters.

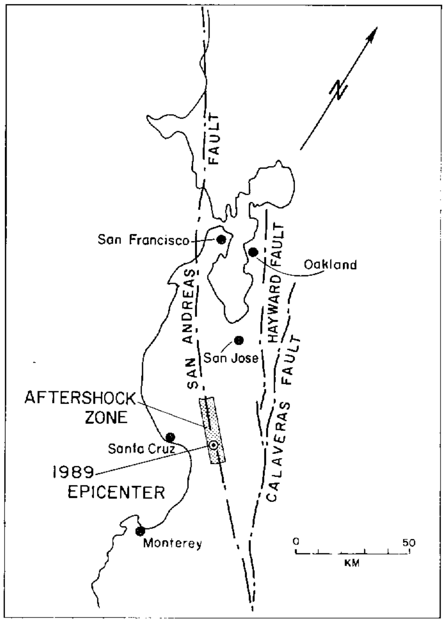

Figure 1. Map showing the location of the October 17, 1989 Loma Prieta earthquake epicenter and aftershock zone. The traces of the San Andreas, Calaveras, and Hayward faults in the Bay area are also shown. Any of these faults could be sources of earthquakes that would be devastating to the Bay area.

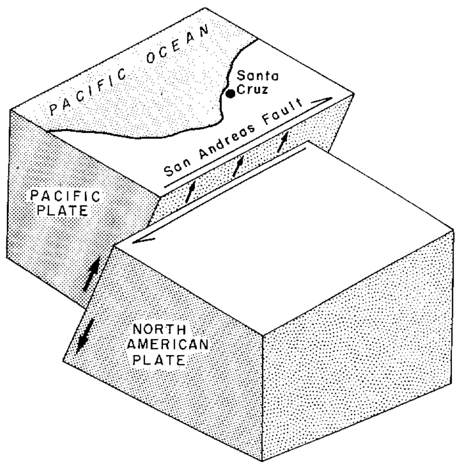

Figure 2. Block diagram portraying the relative motion of the Pacific and North American plates during the Loma Prieta earthquake. The Pacific plate moved right and up relative to the North American plate (right-lateral oblique slip) on a 70° west-dipping fault.

The Loma Prieta earthquake occurred along a section of the San Andreas fault that had undergone no earthquakes larger than magnitude 5.0 since 1906. This section of the fault slipped during 1906, but the amount of slip was much smaller than that observed on the fault north of San Francisco. Based on the slip deficit during the 1906 earthquake, the USGS in 1988 identified this section of the fault as a likely candidate for a magnitude 7.0 earthquake during the following 5 years. The Loma Prieta earthquake has probably relieved the strain accumulation on a 40-km section of the San Andreas fault, but it has not decreased the chances for another magnitude 7.0 or larger event in the Bay area on the Calaveras or Hayward faults. Furthermore, a section of the San Andreas fault between San Francisco and Portala Valley (~30 km long) could rupture in a magnitude 6.5 to 7.0 event. The probability of a repeat of the great San Francisco earthquake of 1906 remains very low, however, and is not expected for 30 to 70 years.

The Loma Prieta earthquake was recorded at the Tucson seismic observatory (TUC). The seismic waves from the earthquake were so large that all the instruments were driven off scale for approximately 20 minutes. Ground shaking was recorded for nearly 3 $^1/_2$ hours at TUC. Based on the time it took for the ground shaking to return to normal background level, Tucson seismologists estimated that the magnitude of the earthquake was 6.8.

Reference

U.S. Geological Survey, Working Group on California Earthquake Probabilities, 1988, Probabilities of large earthquakes occurring in California on the San Andreas fault: Open-File Report 88-398, 62 p.

Anaconda Geologic Data Now Available to the Public

The records of the Anaconda Company's Geological Department (1895 to 1985) are available for public use at the University of Wyoming's American Heritage Center. The collection contains data from most of the major mining areas in the world and comprises prospect and mine evaluations, operating records, and regional studies. The records include 4,245 documents and 851 maps on the mineralogy and geology of Arizona.

The International Archive of Economic Geology (IAEG) at the American Heritage Center is a repository and research facility for original manuscripts from the field of economic geology. In addition to the Anaconda Collection, the IAEG contains files from more than 170 geologists and corporations. The collection has been described in a computer inventory that allows access to its 1.8 million documents and maps. Printouts tailored to specific inquiries are available for a fee.

For more information, contact Dr. Daniel N. Miller, Jr., Director, or Ms. Brigid McGowan, International Archive of Economic Geology, University of Wyoming, Box 3924, Laramie, WY 82071; tel: (307) 766-3704.

The Most Significant Earthquakes in U.S. History

Before the Loma Prieta (San Francisco) earthquake occurred on October 17, 1989, the U.S. Geological Survey (USGS) compiled a list of the 15 most significant earthquakes in the history of the United States. Selection was based on a combination of magnitude, damage, and casualties. The magnitude 7.1 Loma Prieta earthquake, which caused an estimated $4 billion in damage and 66 deaths, would undoubtedly have been included in this list.

Earthquakes are measured in two basic ways: magnitude and intensity. Magnitude is an instrumental measure of the amount of energy released by an earthquake, as indicated by ground motion. It is determined from the logarithm of the amplitude of earthquake waves recorded by seismographs. The Richter magnitude scale, expressed in whole numbers and decimal fractions, theoretically has no upper limit; however, the largest earthquakes ever recorded had magnitudes of less than 10. The Modified Mercalli Scale (MMS) of intensity uses Roman numerals and is based on human judgment of the amount of damage and effects caused by earthquakes. It ranges from I (not felt) to XII (almost total destruction of manmade structures).

The 15 most significant earthquakes in U.S. history, listed in chronological order, are as follows:

(1) **Cape Ann, Mass., Nov. 18, 1755**--Estimated magnitude, 6.0; maximum MMS intensity, VIII. This earthquake was centered in the Atlantic Ocean, 200 miles east of Cape Ann. It was felt over 400,000 square miles, from Nova Scotia south to Chesapeake Bay and from Lake George, N.Y. east into the Atlantic. Damage was heaviest on Cape Ann and in Boston, with about 100 chimneys destroyed.

(2) **New Madrid, Mo., 1811-12**--Estimated magnitudes, 8.4 to 8.7; maximum MMS intensity, XI. In the most violent series of earthquakes in U.S. history, three earthquakes (counted here as one) hit the New Madrid seismic zone in southeastern Missouri and northeastern Arkansas on Dec. 16, 1811, and Jan. 23 and Feb. 7, 1812. Damage and casualties were not great because the area was sparsely populated. The earthquakes, however, were felt over the entire United States east of the Mississippi River and probably far to the west and caused extensive changes in the land surface.

(3) **Virgin Islands, Nov. 18, 1867**--Estimated magnitude, 7.5; maximum MMS intensity, VIII. This earthquake was felt from the Dominican Republic to the Leeward Islands. Property damage, which occurred in the Virgin Islands and Puerto Rico, was partly caused by 20-foot sea waves triggered by the earthquake.

(4) **Charleston, S.C., Aug. 31, 1886**--Estimated magnitude, 6.6; maximum MMS intensity, X. This earthquake killed 60 persons. Most buildings in the Charleston area were damaged or destroyed; losses totalled $20 million. It was felt in New York City; Boston; Milwaukee; Havana, Cuba; and Ontario, Canada.

(5) **Charleston, Mo., Oct. 31, 1895**--Estimated magnitude, 6.2; maximum MMS intensity, IX. This earthquake occurred near the junction of the Mississippi and Ohio Rivers and was the strongest shock in the New Madrid seismic zone since the earthquakes in 1811-12. It was felt over 1 million square miles in 23 states and Canada, caused considerable damage, and created a four-acre lake near Charleston.

(6) **San Francisco, Calif., April 18, 1906**-Estimated magnitude, 8.3; maximum MMS intensity, XI. Although known as the San Francisco earthquake, the 1906 shock actually ruptured the San Andreas fault along a 270-mile segment from San Benito County north to Humboldt County. Fault slip was up to 21 feet in Marin County. Damage was estimated at more than $24 million, from both the earthquake and fires that followed in San Francisco. More than 700 persons died.

(7) **Mona Passage, Puerto Rico, Oct. 11, 1918**--Estimated magnitude, 7.5; maximum MMS intensity, IX. This earthquake was one of the most violent recorded on Puerto Rico and was followed by a tsunami that drowned many persons. The death toll was 116; damage was estimated at $4 million.

(8) **Long Beach, Calif., March 10, 1933**--Estimated magnitude, 6.2; maximum MMS intensity, VIII. This earthquake was one of the most destructive in the United States because it was in a heavily settled area with many poorly constructed buildings, including schools. About 115 persons were killed and hundreds more were injured. Damage was estimated at $40 million. The earthquake led to stricter construction codes in California to mitigate earthquake damage.

(9) **Olympia, Wash., April 13, 1949**--Estimated magnitude, 7.1; maximum MMS intensity, VIII. This earthquake caused heavy damage in Washington and Oregon, killed eight persons, and injured many others. The earthquake was felt eastward to western Montana and south to Cape Blanco, Oregon.

(10) **Hebgen Lake, Mont., Aug. 17, 1959**--Estimated magnitude, 7.3; maximum MMS intensity, X. This was the strongest recorded earthquake in Montana. It was felt over 600,000 square miles, from Seattle to Banff, Canada and from Dickinson, N. Dak. to Provo, Utah. It caused massive waves on Hebgen Lake that did not subside for 12 hours. It also caused a massive landslide that blocked the Madison River canyon, creating a large lake. At least 28 persons were killed. Damage was extensive to summer homes and highways in the region.

(11) **Prince William Sound, Alaska, March 27, 1964**--Estimated magnitude, 8.4; maximum MMS intensity, X. This Good Friday earthquake is the second strongest in the world during the 20th century. It was topped by an 8.6-magnitude earthquake in Chile in 1960. The Alaska earthquake triggered extensive landslides and generated tsunamis. It caused an estimated $311 million in damage in Anchorage and south-central Alaska and killed 131 persons.

(12) **Seattle, Wash., April 29, 1965**--Estimated magnitude, 6.5; maximum MMS intensity, VIII. This earthquake was felt over 130,00 square miles of Washington, Oregon, Idaho, Montana, and British Columbia. Seven persons died; damage was estimated at $12.5 million.

(13) **San Fernando, Calif., Feb. 9, 1971**--Estimated magnitude, 6.6; maximum MMS intensity, XI. This earthquake killed 65 persons, injured many others, and caused $1 billion in damage in the Los Angeles area. As a result of this earthquake and the Alaskan tremor in 1964, the Federal government greatly expanded its earthquake research and reevaluated seismic design for hospitals, emergency clinics, and other critical facilities.

(14) **Coalinga, Calif., May 2, 1983**--Estimated magnitude, 6.7; maximum MMS intensity, VIII. This earthquake injured 45 persons and caused $31 million in damage, with the worst damage occurring in downtown Coalinga. The earthquake was felt from Los Angeles to Sacramento and from San Francisco to Reno, Nevada.

(15) **Borah Peak, Idaho, Oct. 25, 1983**--Estimated magnitude, 7.0; maximum MMS intensity, IX. This earthquake was the largest recorded in Idaho. It was felt over 330,000 square miles. Two children were killed and damage was estimated at $12.5 million.

New AZGS Publications

The following publications may be purchased from the Arizona Geological Survey (AZGS), 845 N. Park Ave., #100, Tucson, AZ 85719. For price information on these and other publications, call the AZGS office at (602) 882-4795.

The Contributed Report series was created in January 1989 for reports written by non-AZGS geologists that are considered to be significant additions to the geologic literature on Arizona. This series title describes more accurately the source and status of these publications. Reports of this nature donated before 1989 were placed in the AZGS Open-File Report series. This latter series is now devoted to reports written by AZGS personnel. Many contributed reports are obscure and would not be readily available to the public if they were not placed in this series.

Scarborough, Robert, and Meader, Norman, 1981 [1989], Geologic map of the northern Plomosa Mountains, Yuma [La Paz] County, Arizona: Contributed Map CM-89-D, scale 1:24,000.

The northern Plomosa Mountains consist of a large fault block of dominantly crystalline rock that has been tilted to the south and is bounded on the east and north by a low-angle normal fault known as the Plomosa detachment fault. The hanging wall of the Plomosa fault comprises a variety of crystalline rocks, metamorphosed and multiply deformed Paleozoic and Mesozoic rocks, and Miocene volcanic and sedimentary rocks. Numerous Tertiary mineral deposits are associated with shear zones in the northern part of the range. This map is the only geologic map of the entire northern Plomosa Mountains.

Maynard, S.R., 1989, Geologic map and cross sections of the southwestern part of the New River Mountains, Arizona: Contributed Map CM-89-E, scale 1:12,000, 2 sheets.

This detailed geologic map covers the southern end of the Moore Gulch shear zone, a complex zone of Proterozoic deformation that separates contrasting Proterozoic rocks and represents an important tectonic feature. Tertiary sedimentary and volcanic rocks are also present in the range.

Chenoweth, W.L., 1989, The access road program of the U.S. Atomic Energy Commission in Arizona: Contributed Report CR-89-A, 4 p.

The exploration activities of the U.S. Atomic Energy Commission (AEC) during the 1950's are well documented in AEC reports. The program of constructing and improving access roads to exploration and mining areas, however, is less known. From 1951 to 1958, some 90 projects affecting 1,253 miles of road were undertaken in Arizona, Colorado, New Mexico, South Dakota, Utah, and Wyoming. These projects cost $17 million, $14 million of which the AEC provided. Seven projects, all totally funded by the AEC, were conducted in Arizona: two in Gila County and five on the Navajo Indian Reservation in Apache County. This report summarizes those projects.

Chenoweth, W.L., 1989, The Carrizo "gold" mine: Contributed Report CR-89-B, 26 p.

Herbert E. Gregory, in his classic 1917 report on the Navajo Indian Reservation, mentions that silver and gold were discovered in the Carrizo Mountains. Gregory did not locate this deposit, nor is it referenced elsewhere in the literature. Some old mine workings, once thought to be related to uranium-vanadium prospecting, are believed to be the so-called Carrizo "gold" mine. Their history and geologic setting are summarized in this report.

Chenoweth, W.L., 1989, The geology and production history of uranium deposits in the Salt Wash Member of the Morrison Formation near Rough Rock, Apache County, Arizona: Contributed Report CR-89-C, 7 p.

The Salt Wash Member of the Jurassic Morrison Formation contains significant uranium-vanadium deposits in the Lukachukai Mountains in northeastern Apache County. North of there, smaller deposits have been mined near the Carrizo Mountains. During the uranium boom of the 1950's, some uranium was also mined from the Salt Wash near Rough Rock Trading Post. This report details the geologic setting and production history of these latter deposits.

Gregg, C.C., and Evensen, C.S., 1989, Maps of the underground workings, Monument No. 2 mine, Apache County, Arizona, with a text by W.L. Chenoweth: Contributed Report CR-89-D, 35 p.

During 1953 and 1954, the two primary authors, geologists with the U.S. Atomic Energy Commission, mapped the underground mine workings of the Monument No. 2 uranium-vanadium mine on the Navajo Indian Reservation. The maps are of historical value because the underground workings were later destroyed by open-pit mining. In addition to the maps, this report includes information on the geologic setting and production history of the mine.

Reynolds, S.J., Spencer, J.E., Laubach, S.E., Cunningham, Dickson, and Richard, S.M., 1989, Geologic map, geologic evolution, and mineral deposits of the Granite Wash Mountains, west-central Arizona: Open-File Report 89-4, 46 p., scale 1:24,000.

The Granite Wash Mountains in west-central Arizona are part of the Maria fold-and-thrust belt, a belt of large folds and major thrust faults that trends east-west through west-central Arizona and southeastern California. In the Granite Wash Mountains, late Mesozoic deformation related to the Maria belt affected a diverse suite of rocks, including Proterozoic crystalline rocks, Paleozoic carbonate and quartzose clastic rocks, and Mesozoic sedimentary, volcanic, plutonic, and hypabyssal rocks. This deformation was mostly deep seated and produced an assortment of folds, cleavages, and ductile and brittle shear zones. Several discrete episodes of deformation occurred, resulting in refolded folds, folded and refolded thrust faults, and complex repetition, attenuation, and truncation of stratigraphic sequences. Deformation and metamorphism were followed by emplacement of two Late Cretaceous intrusions and numerous dikes.

Mineralization includes gold deposits associated with quartz veins, shear zones, and silicification; tungsten deposits associated with quartz veins and shear zones; and quartz-kyanite deposits similar to those in the southern Appalachian Mountains that are associated with large gold deposits.

The geology of the Granite Wash Mountains was mapped between 1982 and 1988 as part of the U.S. Geological Survey/AZGS Cooperative Geologic Mapping (COGEOMAP) program. This report, which includes a 1:24,000-scale map, describes major findings about stratigraphy, structure, metamorphism, and mineral deposits in the area.

Welty, J.W., Reynolds, S.J., Spencer, J.E., Horstman, K.C., and Trapp, R.A., 1989, List of selected references on the geology and mineral resources of Arizona: Open-File Report 89-5, 162 p.

This report, which includes more than 4,500 references, is the first step toward an inclusive bibliography on the geology and mineral resources of Arizona. It was compiled from bibliographies that were previously published by or are currently in-progress at the AZGS. Bibliographic entries are listed alphabetically by author. The list is most useful for finding a reference for which the author is known, but not the date or journal.

McGarvin, T.G., 1989, Publications of the Arizona Bureau of Mines (1915-77) and the Arizona Bureau of Geology and Mineral Technology (1977-88): Open-File Report 89-6, 12 p.

The AZGS was established on July 1, 1988. Its two most recent predecessors were the Arizona Bureau of Geology and Mineral Technology and the Arizona Bureau of Mines. Many of the publications of these antecedent agencies are out of print but available in the AZGS library. This report lists all the publications released by these agencies.

Demsey, K.A., 1989, Geologic map of Quaternary and upper Tertiary alluvium in the Phoenix South 30′ x 60′ quadrangle, Arizona: Open-File Report 89-7, scale 1:100,000.

This map shows the distribution of alluvial deposits of different ages in the Phoenix South 30′ x 60′ quadrangle and provides a basis for evaluating the Quaternary geologic history of the area. The map was compiled from U2 high-altitude aerial photographs (scale 1:129,000), natural-color aerial photographs (scale 1:24,000), and field studies. The project was partially funded by the COGEOMAP program.

Welty, J.W., Reynolds, S.J., and Spencer, J.E., 1989, AZMIN, a digital database compilation for Arizona's metallic mineral districts: Open-File Report 89-8, 42 p., high- or low-density floppy disks.

AZMIN is the result of a 10-year effort to determine a classification method, compile information, and create a digital database for Arizona's metallic mineral districts. In the mineral-district classification used for this database, known deposits are grouped according to geologic and metallogenic criteria rather than the geographic associations used in the traditional mining-district approach.

AZMIN databases and programs were developed on IBM-PC-compatible microcomputers through the use of dBase IV, a database-management program. AZMIN consists of 3 database files and 10 data-manipulation programs that allow the user to search data or display them in various formats. AZMIN includes mineral-district and mine locations, production data, and bibliographic information. This report, the first computer database that the AZGS has offered for sale, includes 42 printed pages of documentation and either high-or low-density, formatted floppy disks, which the user must specify upon ordering.

Geologic Field-Trip Guidebooks

28th IGC (International Geological Congress) Field-Trip Guidebooks. The American Geophysical Union has published 126 guidebooks to distinct geographic regions in North America, including many U.S. national parks. The guidebooks contain road logs, describe geologic features, provide historical information, and discuss the geologic processes operating in each region. For more information, contact the American Geophysical Union, 2000 Florida Ave., N.W., Washington, D.C. 20009; tel: (202) 462-6903.

Union List of Geologic Field-Trip Guidebooks of North America, 5th Edition. This 223-page volume lists more than 6,500 guidebooks for field trips held from 1891 through the end of 1985. It specifies the guidebooks housed in 218 libraries in the United States and Canada and the lending policies of those libraries. The volume also contains geographic and stratigraphic indices. It is available for $60.00 from the American Geological Institute, 4220 King St., Alexandria, VA 22302; tel: (800) 336-4764.

STAFF NOTES

Laurette E. Colton completed a supervisory training program at the (Extended) University of Arizona and received a Certificate in Effective Employee Supervision on November 7. She has been promoted from Clerk Typist III to Administrative Support Supervisor I.

Thomas G. McGarvin gave an overview of the Arizona Geological Survey to the Paleontological Society of Southern Arizona on May 8. He presented talks on Arizona's gold deposits to members of the Desert Gold Diggers and Old Pueblo Lapidary Club on June 6 and October 12, respectively. He also led educators on field trips to view Tucson-area geology on April 1 and 8 and on October 7 and 14. On November 18, he led a field trip to the Tucson Mountains for Saguaro National Monument docents. McGarvin, along with **Larry D. Fellows**, led a field trip, "Applied Geology of the Basin and Range," on November 30 as part of the Phoenix regional meeting of the National Science Teachers Association (NSTA). On December 2, he served as coleader of an NSTA workshop, "Mineral Mysteries and Rock Riddles: Classroom Methods of Identification."

Philip A. Pearthree organized and led a seminar on flood hazards associated with alluvial fans for the fall meeting of the Arizona Floodplain Management Association, held in Tucson September 14-15. The seminar focused on the nature of stream behavior on desert piedmonts and its implications for floodplain management in Arizona.

Stephen J. Reynolds organized or led two field trips to the Tucson Mountains: on April 15 for the Arizona Geological Society and on July 7 for the International Geological Congress. He also gave three talks: "Fluids and Detachment Faults -- Mineralization, Metasomatism, and Structural Aspects" to the New Mexico Institute of Mining and Technology and New Mexico Bureau of Mines and Mineral Resources on April 20; "Mesozoic Evolution of Western Arizona" to geologists from Northern Arizona University and the U.S. Geological Survey on May 3; and "Fluids and Faults" to the Arizona Geological Society on July 11.

Jon E. Spencer gave a talk, "Cenozoic Extensional Tectonics of the Mohave-Sonora Region," to the Department of Geology at the University of New Mexico and the New Mexico Bureau of Mines and Mineral Resources on September 20 and 21, respectively. He also served on the Ph.D. research committee for a University of New Mexico graduate student, whose dissertation focused on the geology of the Van Diemon mine area in the Black Mountains of Arizona.

John W. Welty gave a briefing on the status of mineral-resource information on Arizona at the Western Minerals Information Workshop, sponsored by the U.S. Geological Survey and held in Sacramento, Calif. in late March.

Cooperative Geologic Mapping in Arizona: 1989 COGEOMAP Update

by Stephen J. Reynolds
and Michael J. Grubensky
Arizona Geological Survey

A major legislated responsibility of the Arizona Geological Survey (AZGS) is to characterize the geologic framework of Arizona. To help fulfill this responsibility, the AZGS has placed a high priority on geologic mapping, especially on producing high-quality, quadrangle-scale (1:24,000) geologic maps of previously unmapped areas. Such maps increase the understanding of the geologic framework, mineral potential, and geologic hazards of an area by helping to define the stratigraphy, structure, geologic history, and distribution and setting of mineralization and alteration. The quadrangle-scale maps may be used to compile intermediate-scale (e.g., 1:100,000 or 1:250,000) maps to define the regional distribution of mineral resources and geologic hazards and identify areas where additional mapping is needed. Maps at both scales will be used to produce a new 1:500,000-scale geologic map of Arizona.

Since 1984, the AZGS and U.S. Geological Survey (USGS) have participated in the Cooperative Geologic Mapping (COGEOMAP) program. As part of this cost-sharing program, AZGS geologists have concentrated their mapping in the Phoenix 1° x 2° quadrangle (Figure 1) and adjacent parts of west-central Arizona. This region is geologically complex and highly mineralized, but very poorly understood. The Phoenix quadrangle is also the site of rapid urban growth and major construction projects, such as the Palo Verde Nuclear Generating Station, Central Arizona Project, New Waddell Dam, and a hazardous and toxic waste repository.

During the past 9 years, AZGS geologists have completed 1:24,000-scale geologic maps of the Belmont, Big Horn, Granite Wash, Hieroglyphic, Little Harquahala, Maricopa, South, Vulture, and Wickenburg Mountains, Aguila Ridge-Bullard Peak area, and Merritt Hills (Figure 1). Parts of the Bouse Hills and Buckskin, Harcuvar, Harquahala, and White Tank Mountains have also been mapped. From this mapping, major geologic discoveries have been made, including (1) previously unknown Mesozoic sequences and an early Mesozoic uplift event; (2) the Maria fold-and-thrust belt, a previously unrecognized Mesozoic thrust belt; (3) a suite of quartz-kyanite rocks similar to those associated with gold on the Piedmont of the southeastern United States; (4) low-angle normal (detachment) faults that have regional tectonic and economic significance; and (5) previously undescribed areas of alteration and mineralization.

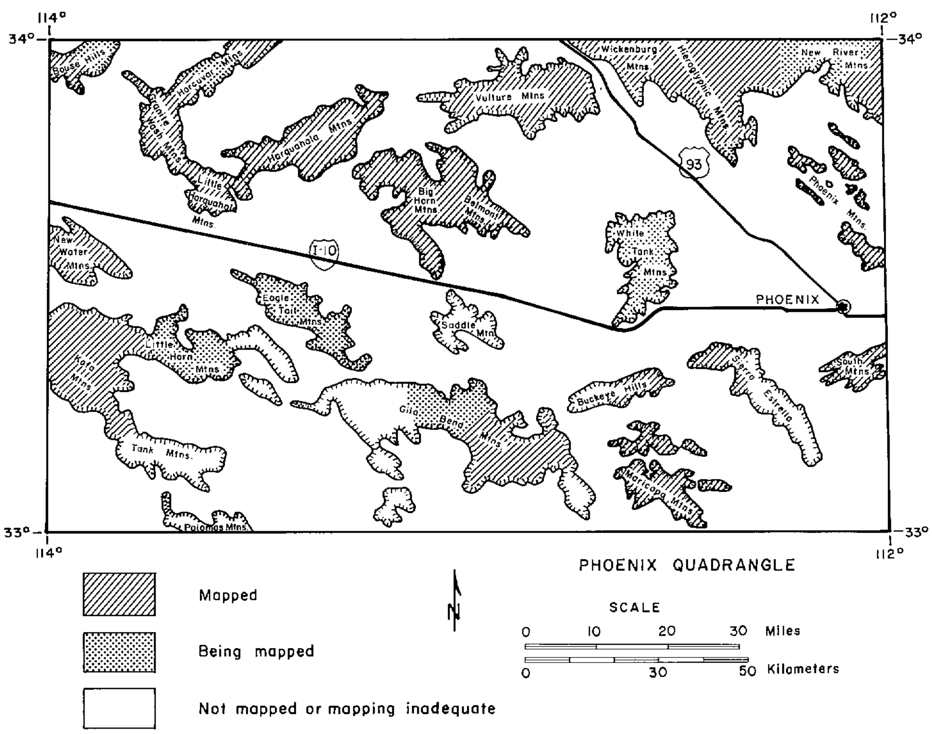

Figure 1. Status of geologic mapping in the Phoenix 1° x 2° quadrangle.

1984-88 COGEOMAP Projects

During the 1984-85 COGEOMAP project, AZGS geologists mapped the Bighorn and Belmont Mountains at a scale of 1:24,000 (AZGS Open-File Report 85-14) and prepared a report containing geologic, geochemical, and fluid-inclusion data on mineral deposits in the area (AZGS Open-File Report 85-17). The geologic maps depict numerous normal faults that cut moderately tilted Tertiary volcanic rocks and their underlying basement.

During 1986 and 1987, AZGS geologists completed 1:24,000-scale maps of the Hieroglyphic, Wickenburg, and northeastern Vulture Mountains (AZGS Open-File Reports 86-10, 87-9, 87-10, and 88-1). These maps show many previously unrecognized faults, Proterozoic banded-iron formations, a large Cretaceous granodioritic pluton, and a Miocene volcanic field. Some normal faults have several kilometers of displacement, which helped to accommodate 150 percent crustal extension. They are commonly the loci of middle Tertiary hydrothermal alteration and mineralization.

1988-90 COGEOMAP Projects

The 1988-89 COGEOMAP project produced a 1:24,000-scale geologic map of the southeastern Vulture Mountains (AZGS Open-File Report 88-9) and the Vulture mine, one of the premier gold deposits in Arizona. Geologic studies (AZGS Open-File Report 88-10 and this issue of *Arizona Geology*) documented that mineralization at the Vulture mine represents a midlevel, pluton-related Cretaceous vein that has been turned on its side by Tertiary fault-block rotation. The top of the orebody was removed by pre-Miocene erosion rather than by faulting, as previous interpretations suggested.

The 1988-89 COGEOMAP project also resulted in the publication of a new, 1:1,000,000-scale, colored geologic map of Arizona (AZGS Map 26) and the release of three 1:100,000-scale maps of Quaternary deposits (AZGS Open-File Reports 88-4, 88-17, and 89-7).

The 1989-90 COGEOMAP project, which began on May 1 of this year, has concentrated on completing a 1:24,000-

scale map of the entire Vulture Mountains (AZGS Map 27, in press). This publication, based on field studies conducted from 1986 to 1989, represents a major advance in the knowledge of this important mountain range. The range consists of Miocene volcanic rocks that depositionally overlie a basement of Proterozoic crystalline rocks and a large Cretaceous granitoid pluton. Miocene crustal extension formed a series of north-trending, tilted fault blocks bounded by low-angle normal faults. The Tertiary units have been steeply tilted in much of the range; each fault block exposes an originally vertical cross section through the Miocene volcanic field. In such cross sections, rhyolitic lava flows can be traced downward into their original feeder zones, now represented by rhyolitic dikes. Similar cross sections through the Cretaceous pluton are exposed in the tilt blocks.

Two distinct suites of Miocene rhyolitic volcanic rocks have been identified in the Vulture Mountains: an older 1- to 1.5-kilometer-thick sequence that predates extension and a younger thinner sequence that postdates much extension. Dikes associated with the younger suite commonly intrude along low-angle faults and are extensively K-metasomatized. A unique series of Sr- and U-bearing lacustrine rocks overlies the younger rhyolitic suite in the western end of the range. Even younger, largely posttectonic basalts unconformably overlie tilted rocks in several parts of the range.

The AZGS recently released a 1:24,000-scale map of the Granite Wash Mountains, one of the most structurally complex mountain ranges in the western United States. This map is accompanied by a detailed description of rock units, structural evolution, and mineral deposits (AZGS Open-File Report 89-4). The range consists of a stack of imbricate, ductile thrust faults that juxtaposed Proterozoic and Jurassic crystalline rocks discordantly over an upturned section of Paleozoic and Mesozoic supracrustal rocks. The rocks show evidence of three episodes of thrusting, each with a different transport direction. The thrust sheets were later folded by two generations of large folds, some of which have amplitudes of 1 kilometer. Massive quartz-kyanite rocks were discovered in four areas; these rocks are similar to those associated with gold on the Piedmont of the southeastern United States.

AZGS geologists will spend the 1989-90 winter field season mapping the New River area and White Tank Mountains to complete the Phoenix North 1:100,000-scale quadrangle map (northeastern quarter of the Phoenix 1° x 2° quadrangle). Continued mapping in the western Harcuvar Mountains and Bouse Hills will complete the Salome 1:100,000-scale quadrangle map (northwestern quarter of the Phoenix 1° x 2° quadrangle). AZGS geologists will also start mapping the geology of the Little Horn Mountains in the southwestern quarter of the Phoenix 1° x 2° quadrangle. This range is an eastward continuation of the middle Tertiary Kofa volcanic field and contains several important areas of Tertiary precious-metal mineralization.

After the New River and Little Horn Mountains are mapped, the AZGS will have achieved one long-term goal: to produce a regional northeast-trending transect from the Kofa Mountains in southwestern Arizona to the edge of the Transition Zone. This transect, which includes the Kofa, Little Horn, Big Horn, Belmont, Vulture, Wickenburg, and Hieroglyphic Mountains and New River area, will enable AZGS and USGS geologists to address such fundamental issues as (1) the tectonic significance of the Basin and Range Province - Transition Zone boundary, (2) the magnitude of crustal extension in this part of the Basin and Range Province, and (3) the regional controls and timing of mineralization.

OGCC Relocated

The office of the Oil and Gas Conservation Commission has been moved to 5150 N. 16th St., Suite B-141, Phoenix, AZ 85016. The phone number, however, is the same: (602) 255-5161.

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GEOLOGY OF THE VULTURE MINE, ARIZONA

D. C. White

Prescott, Arizona

For presentation at the SME Annual Meeting
Phoenix, Arizona - January 25-28, 1988

Abstract. The Vulture Mine near Wickenburg, Arizona was a major gold producer from 1863 to 1942, having yielded about 11,000 kg Au and 8,000 kg Ag. Gold occurs as coarse native metal and electrum in quartz veins and also finely disseminated within a quartz monzonite sill and its silicified wall rock. The sill is semi-conformable within a Proterozoic volcaniclastic-dominated sequence, all dipping north about 35°. Early mining focused on the vein-hosted gold, particularly in the immediate hanging wall and footwall of the sill. Later efforts included some open-pitting of the outcropping sill and adjacent altered and mineralized rock. Two sets of post-mineral faults have complicated the orebody geometry.

The sill is a 350m long apophysis from a quartz monzonite stock to the west of the mine area. The stock has been dated at 85 my and contains abundant lesser gold occurrences in its core and about its margins. The Proterozoic rocks are notably lean in precious metals except where altered in proximity to the Cretaceous stock and sill. Circumstances dictate an interpretation of epigenetic mineralization related to the Laramide intrusion.

Introduction

The Vulture Mine is 17 km southwest of Wickenburg in Maricopa County, Arizona and accessible by the Vulture Mine Road south from State Highway 60 (Figure 1). Despite its preeminence as a gold producer, it has not been well understood because very little geology was recorded during its major period of production in the late nineteenth century, and because it has long been patented and guarded, effectively preventing modern-day study. Only exploration in the 1930's and 1980's accumulated much information of substance on the nature of the

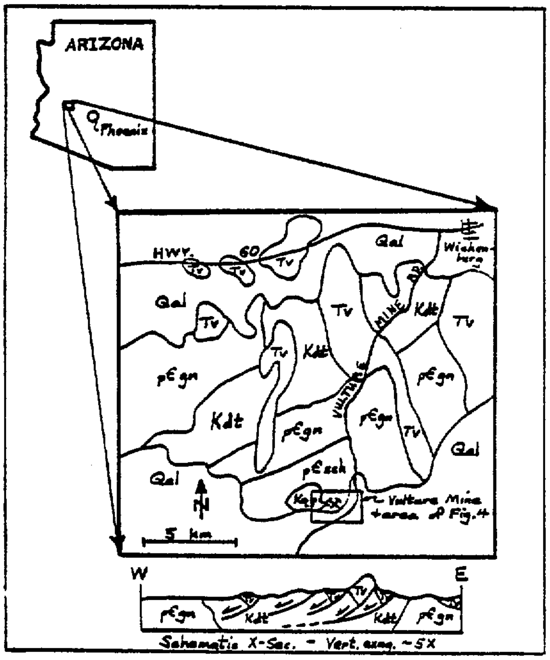

Figure 1: Location Map, and regional geology of the Vulture Mtns after Rehrig, et. al., 1980.