

Arizona Geological Survey

ARIZONA GEOLOGY

(formerly *Fieldnotes*)

Vol. 19, No. 4

Investigations • Service • Information

Winter 1989

Geology of the Vulture Gold Mine

by Jon E. Spencer, Stephen J. Reynolds,
Michael J. Grubensky, John T. Duncan
Arizona Geological Survey
and Don C. White
521 E. Willis St.
Prescott, AZ 86301

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).

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 (COGEMAP) 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-

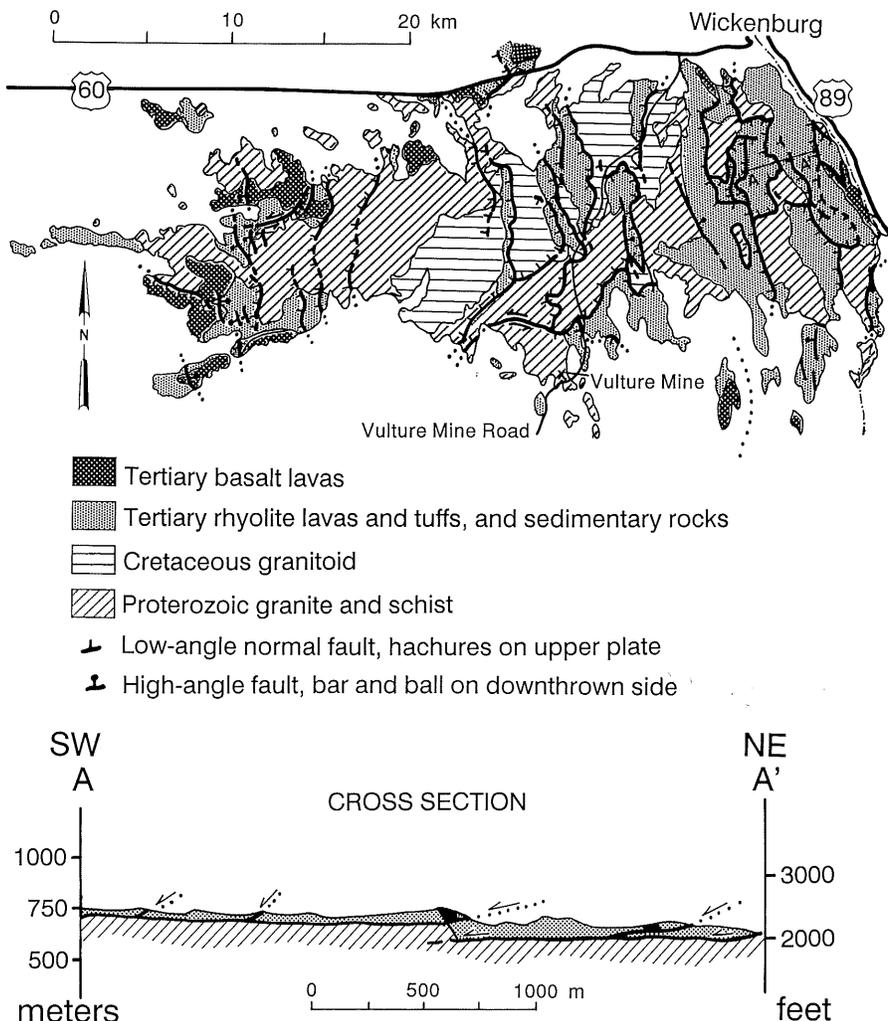


Figure 1. Simplified geologic map and cross section of the Vulture Mountains (from Grubensky and others, 1987; Grubensky and Reynolds, 1988; and M.J. Grubensky, unpublished mapping).

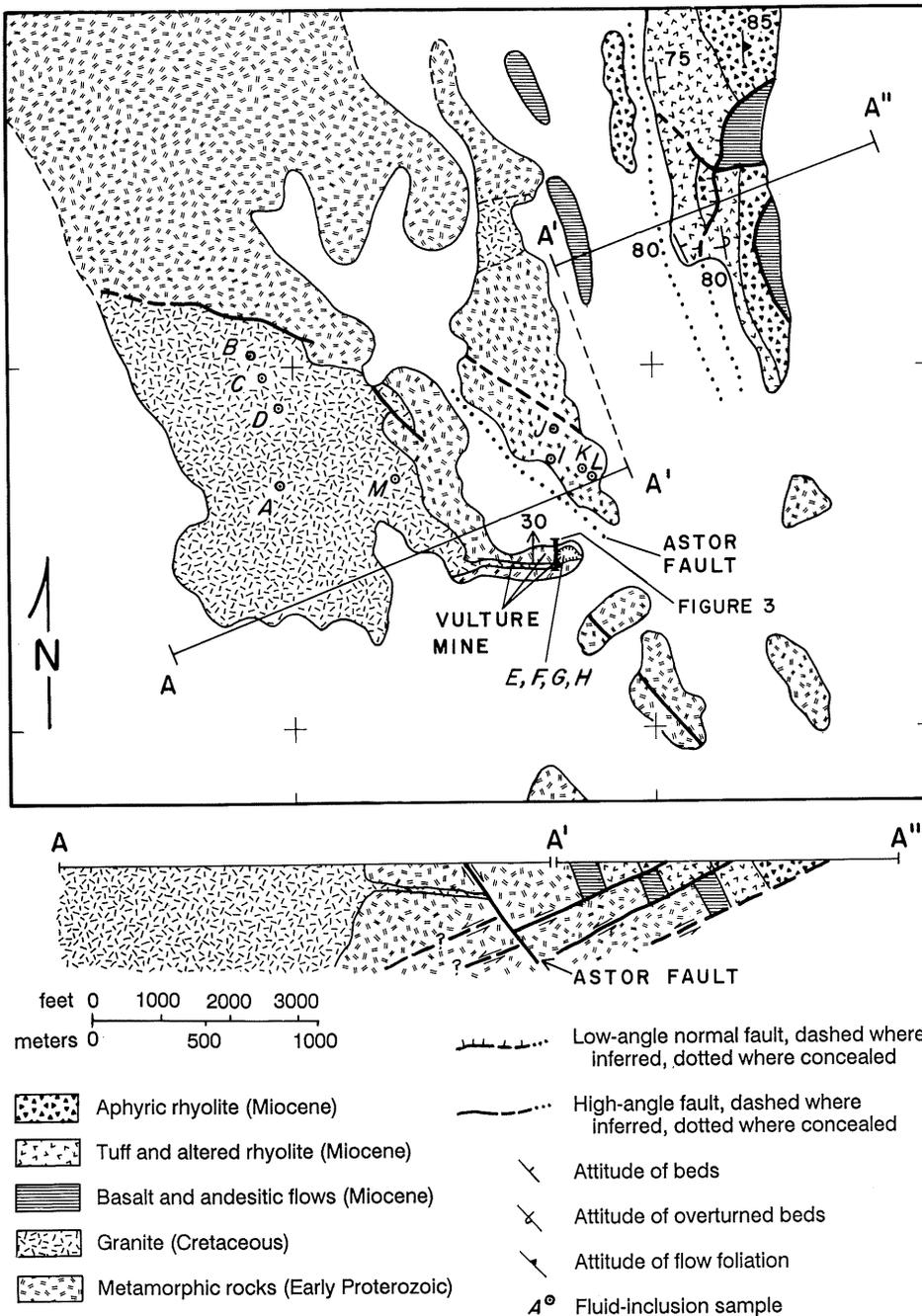


Figure 2. Simplified geologic map of the Vulture mine area and fluid-inclusion sample locations.

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 pre-rotation 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-

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 Geologic cross section through the Vulture mine (modified from White, 1988 and unpublished data).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

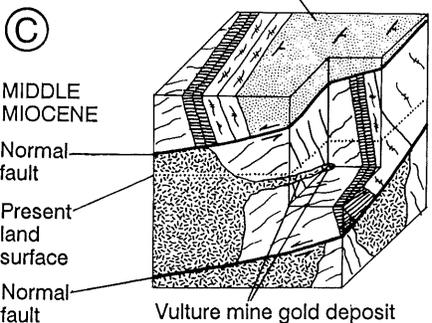
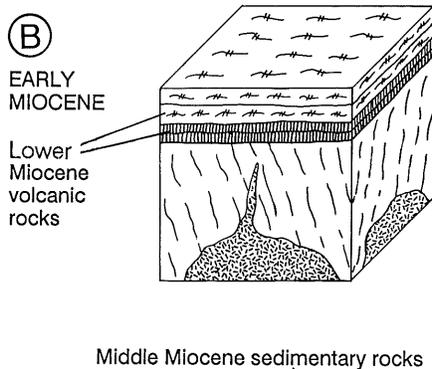
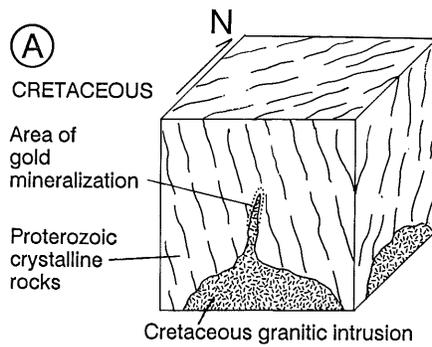
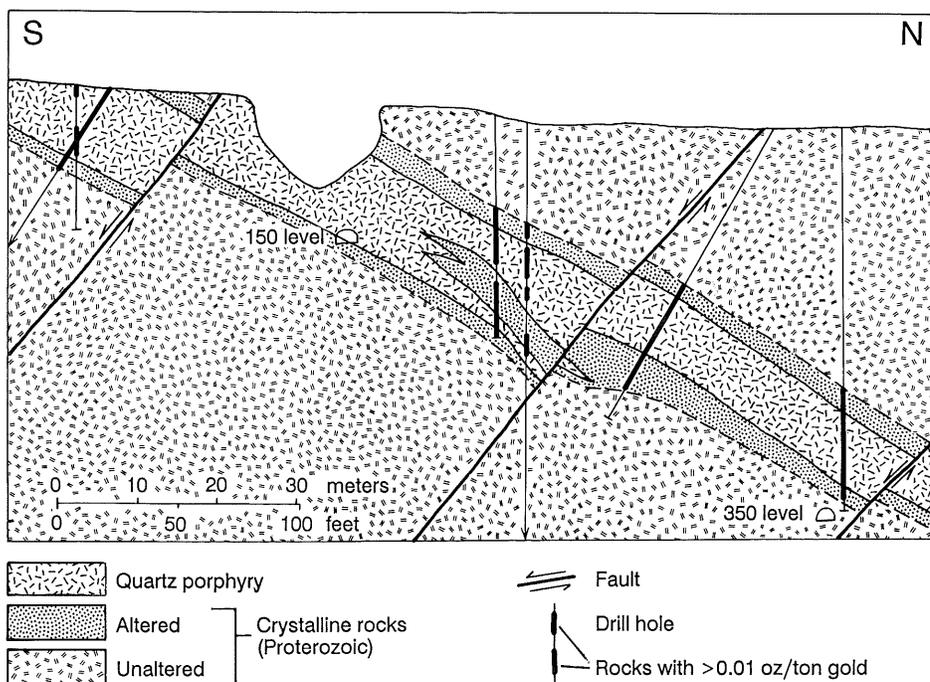
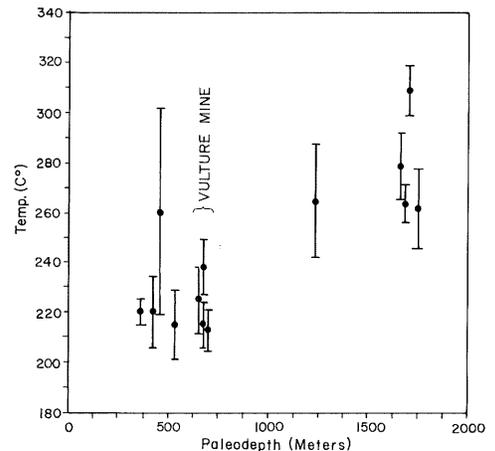
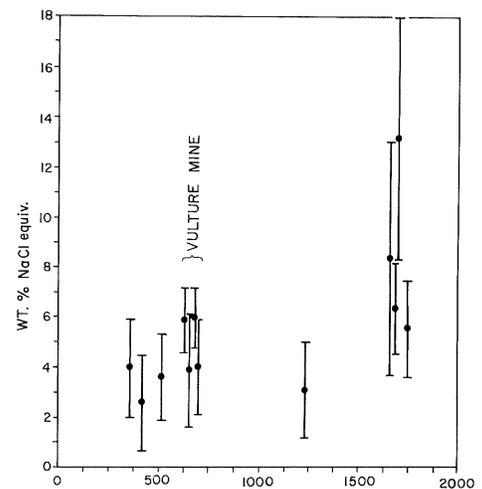


Figure 4 (left). Evolutionary block diagram of the Vulture mine area. Although only one generation of normal faults is shown, rotation probably occurred by movement on two or more generations of normal faults and is more complex than is shown here.

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.



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).

References

Grubensky, M.J., and Reynolds, S.J., 1988, Geologic map of the southeastern Vulture Mountains, west-central Arizona: Arizona Geological Survey Open-File Report 88-9, 16 p., scale 1:24,000.

Grubensky, M.J., Stimac, J.A., Reynolds, S.J., and Richard, S.M., 1987, Geologic map of the northeastern Vulture Mountains and vicinity, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-10, 7 p., scale 1:24,000.

Lowell, J.D., 1968, Geology of the Kalamazoo orebody, San Manuel district, Arizona: Economic Geology, v. 63, p. 645-654.

Rehrig, W.A., Shafiqullah, M., and Damon, P.E., 1980, Geochronology, geology, and listric normal faulting of the Vulture Mountains, Maricopa County, Arizona, in Jenney, J.P., and Stone, Claudia, eds., Studies in western Arizona: Arizona Geological Society Digest, v. 12, p. 89-110.

Reynolds, S.J., Spencer, J.E., DeWitt, Ed, White, D.C., and Grubensky, M.J., 1988, Geologic map of the Vulture mine area, Vulture Mountains, west-central Arizona: Arizona Geological Survey Open-File Report 88-10, 4 p., scale 1:24,000.

Stimac, J.A., Fryxell, J.E., Reynolds, S.J., Richard, S.M., Grubensky, M.J., and Scott, E.A., 1987, Geologic map of the Wickenburg, southern Buckhorn, and northwestern Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-9, 13 p., scale 1:24,000, 2 sheets.

White, Don, 1988, Geology of the Vulture mine, Arizona: American Institute of Mining, Metallurgical, and Petroleum Engineers, Society of Mining Engineers Preprint 88-44, 5 p.

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

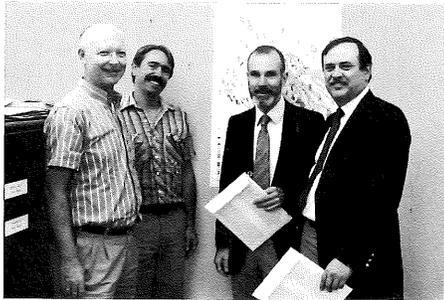


Figure 1. Representatives from the AZGS and USGS discuss the Cooperative Geologic Mapping (COGEMAP) program. Left to right: Larry Fellows (AZGS Director and State Geologist), Steve Reynolds (AZGS Research Geologist), Ben Morgan (USGS Chief Geologist, Reston), and Dave Russ (USGS Assistant Chief Geologist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