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Geologic maps are perhaps the most fundamental sources of geologic information. They depict the surficial distribution of rock types and the relationships among them and may reveal volumes about an area's geologic history. Geologic maps are valuable tools for mineral exploration, land-use planning, geologic research, and other scientific and societal endeavors.

Many, perhaps most, individuals who use geologic maps tend to view them as geologic *data* and do not appreciate the degree to which maps represent *interpretations* of field observations. The interpretive character of geologic maps is commonly revealed when previously mapped areas are remapped, and the two maps do not agree about many geologic aspects. These discrepancies may lead to radically different inferences about the geologic history and subsurface geology, as well as dissimilar mineral-exploration strategies and assessments of potential geologic hazards. Recent remapping of the northern Dragoon Mountains has yielded geologic interpretations that differ from those of previous mapping efforts.

The Dragoon Mountains in Cochise County (Figure 1) are among the most

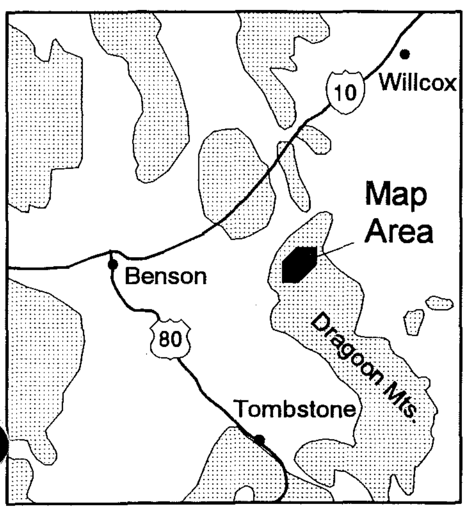

Figure 1. Location of study area (Figures 3 and 4) in Cochise County, southeastern Arizona.

Geologic Maps as Interpretive Studies: An Example From the Dragoon Mountains

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structurally complex ranges in southeastern Arizona. Color geologic maps of the northern part of the range (Gilluly, 1956; Drewes, 1981, 1987) depicted a highly slivered belt of rocks intruded by the middle Tertiary Stronghold Granite (Figure 2). In the north-central Dragoon Mountains, the Fourr Canyon Fault has placed siltstone, sandstone, and conglomerate of the Bisbee Group over steeply dipping and highly faulted pre-Tertiary rocks. Drewes (1981, 1987) interpreted this fault as a Late Cretaceous thrust fault.

In the fall of 1992, Dr. George Gehrels of the Department of Geosciences, University of Arizona, spent 6 days teaching an advanced field-mapping class in the north-central Dragoon Mountains. Dr. Jon Spencer, Arizona Geological Survey research geologist, also mapped the area with the class. Maps produced by the authors of this report were generalized and compiled into one map at 1:24,000 scale (Figure 3). Comparison of this map with the maps of Drewes (1981, 1987; Figure 4) reveals significant differences.

We interpret the Late Cretaceous, Fourr Canyon thrust fault of Drewes as a middle Tertiary, moderate- to low-angle normal fault. Our interpretation is based on two observations:

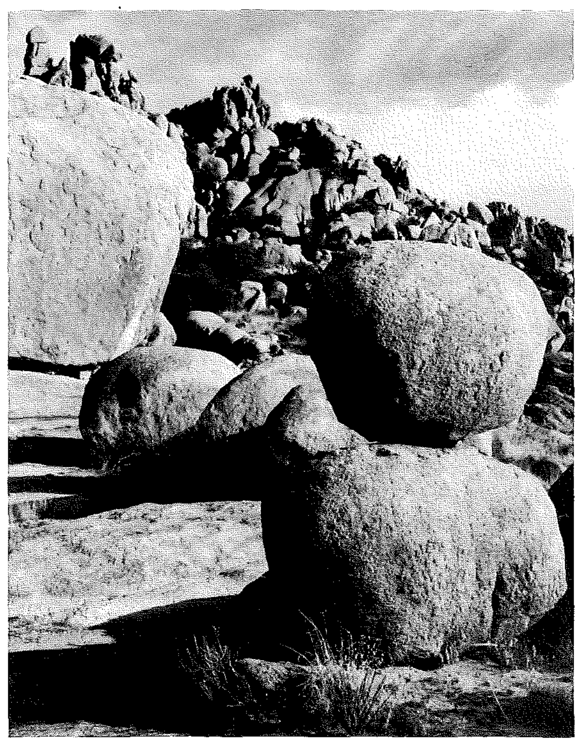

Figure 2. Cochise Stronghold in the northern Dragoon Mountains is the type locality of the Stronghold Granite. Weathering has chiseled the granite into rounded domes and spires. Sheltered by towering crags and watered by permanent springs, the area is a natural fortress that served as a hiding place for the Chiricahua Apache Tribe in the 1800's. The area was named for Cochise, a famous chief, who is supposedly buried there. Photo © 1993 Peter Kresan.

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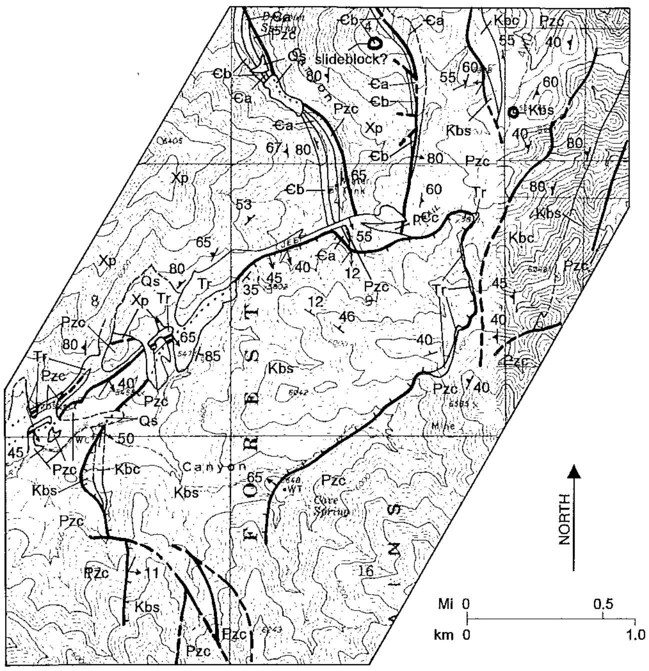

Figure 3. Geologic map of study area in northern Dragoon Mountains compiled from authors' field maps. See legend below.

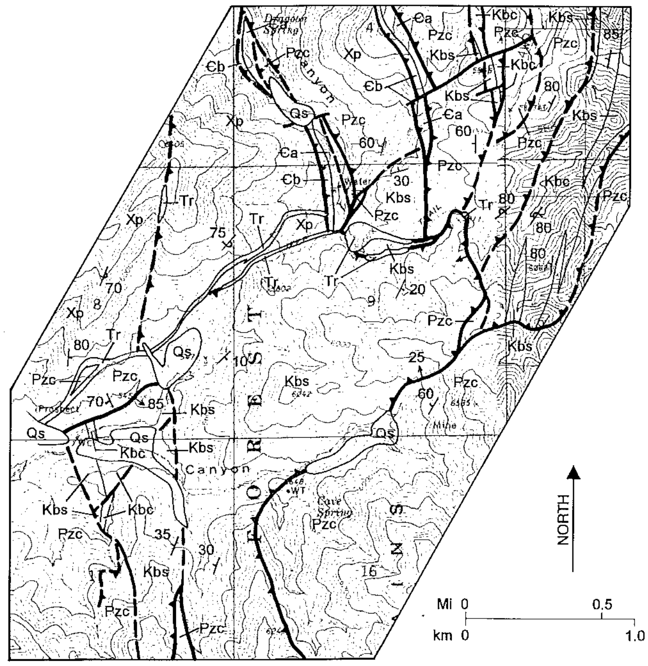

Figure 4. Geologic map of study area simplified from Plate 2 in Drewes (1981). See legend below.

MAP UNITS

Qs	Surficial deposits (Quaternary)
Tr	Rhyolitic intrusive rocks (Tertiary)
Kbs	Sandstone and siltstone of the Bisbee Group (Cretaceous)
Kbc	Conglomerate of the Bisbee Group (Cretaceous)
Pzc	Carbonate sedimentary rocks with minor amounts of clastic rocks, undivided (Paleozoic)
Ca	Phyllite, fine-grained metasandstone, and siliceous carbonate rocks of the Abrigo Formation (Cambrian)
Cb	Bolsa Quartzite (Cambrian)
Xp	Pinal Schist (Proterozoic)

MAP SYMBOLS

46	Strike and dip of beds
80	Strike and dip of overturned beds
55 60	Strike and dip of foliation and trend of lineation
40	High-angle fault, showing fault dip and trend of striations on fault surface. Dashed where approximately located; dotted where concealed.
40	Moderate- to low-angle normal fault, showing fault dip and trend of striations on fault surface. Dashed where approximately located; dotted where concealed.
40	Thrust fault, showing dip

(1) Cretaceous Bisbee Group strata above the Fourr Canyon Fault are lithified but essentially unmetamorphosed. Primary porosity appears to have been preserved in some samples of sandstone, which indicates that the rocks have not been subjected to significant heat or pressure.

In contrast, rocks below the fault are metamorphosed and penetratively deformed. Carbonate cobbles in the Glance Conglomerate of the Bisbee Group below the fault have been stretched so much that some resemble cigars. Similar deformation has probably affected most of the other carbonate rocks below the fault. Siltstones in the Cambrian Abrigo Formation are now phyllites. Relict bedding in the Proterozoic Pinal Schist is largely obscured by metamorphism. In Figure 3, therefore, all lithologic layering in rocks below the Fourr Canyon Fault is shown as foliation. In contrast, Drewes (1981, 1987) depicted lithologic layering in rocks below the Fourr Canyon Fault as bedding, even in the Pinal Schist (Figure 4).

(2) The Fourr Canyon Fault both truncates and is intruded by rhyolite. Drewes (1987) showed dikes of this rhyolite intruding the middle Tertiary Stronghold Granite southeast of the map area in Figure 4. The dikes are thus no older than middle Tertiary and are probably related to emplacement of the Stronghold Granite. In the study area, the rhyolite is striated and brecciated along parts of the Fourr Canyon Fault. In other areas, however, the rhyolite intrudes the fault and is neither brecciated nor striated. This indicates that rhyolitic intrusion along the fault was approximately synchronous with the latest movement on the fault, which was middle Tertiary.

We conclude that middle Tertiary, moderate- to low-angle normal faulting juxtaposed unmetamorphosed Bisbee Group strata over pre-Tertiary rocks that had been deformed and metamorphosed several kilometers below the Earth's surface before normal faulting removed much of their overburden. In the study area, the Fourr Canyon Fault is keel shaped; the keel strikes northeast and is parallel to striations along the fault. These features indicate that the latest movement on the fault displaced rocks above the fault to the northeast or southwest. Our reinterpretation of the Fourr Canyon Fault as a normal fault is similar to Dickinson's (1984) reinterpretation of the nearby Lime Peak Fault.

Comparison of Figures 3 and 4 reveals other minor differences in the assignment of rock units and in the location and interpretation of the contacts between these units. We interpret the contact between the Cambrian Bolsa Quartzite and the Proterozoic Pinal Schist as depositional in most places, as did Gilluly (1956). In 1981, Drewes

DRAGOON continued on page 7

Geologic Studies Related to the USGS COGEOMAP Program

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For the past 8 years, the U.S. Geological Survey (USGS), through the Cooperative Geologic Mapping (COGEOMAP) program, has provided financial assistance to the Arizona Geological Survey (AZGS) to augment its geologic mapping program. Bedrock geologic mapping funded by this program has been conducted almost entirely in the Phoenix 1° x 2° quadrangle and has typically led to the production of geologic maps at 1:24,000 scale (Figures 1 and 2). Beginning in 1990, the COGEOMAP program provided separate funding for surficial geologic mapping, which has been primarily focused on urban and developing areas in the State (Figure 3). The AZGS has received $495,922 from the USGS since 1984: $422,922 for bedrock geologic mapping and $73,000 for surficial geologic mapping. The COGEOMAP program requires that State geological surveys match Federal funds with State support for mapping projects. The AZGS spent approximately $1,200,000 on geologic mapping and related studies during this period.

The 1992-93 field season is the last year of the COGEOMAP program. It will be replaced by a State mapping program that is a component of the National Geologic Mapping Act (S. 1179 and H.R. 2763; see *Arizona Geology*, Winter 1991 issue, vol. 21, no. 4, p. 7-8, and Summer 1992 issue, vol. 22, no. 2, p. 12). This new program will involve different funding procedures. The list below includes publications that are products of the Arizona COGEOMAP program during the first 7 of its 8 years.

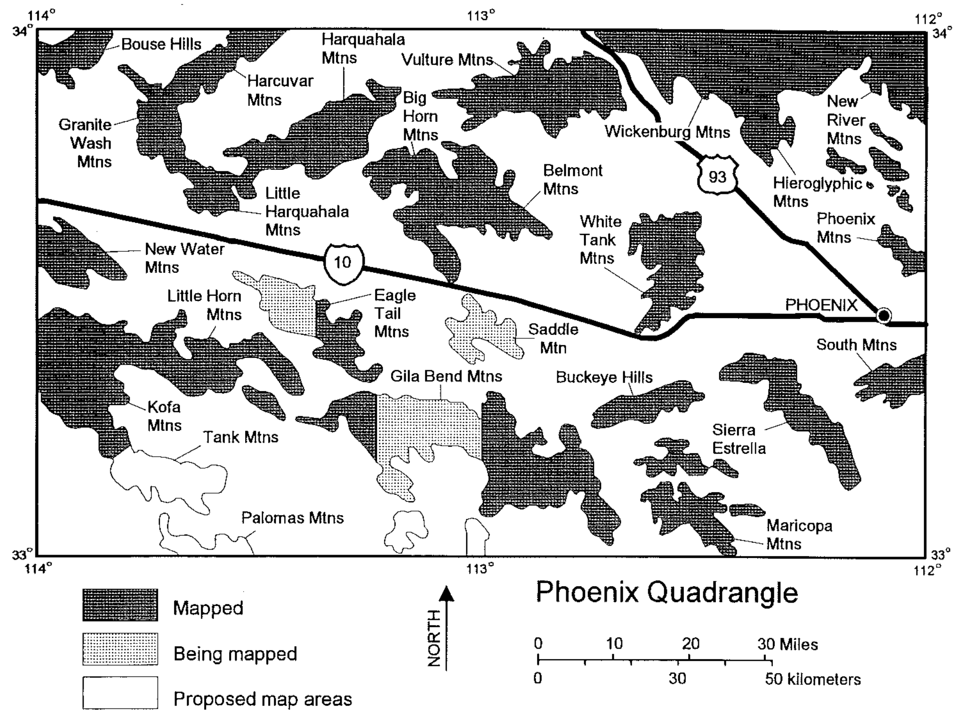


Figure 1. Status of geologic mapping within the Phoenix 1° x 2° quadrangle.

BEDROCK GEOLOGIC-MAPPING PROGRAM

The following are ***geologic maps*** *of areas in the Phoenix 1° x 2° quadrangle that were produced largely or entirely by AZGS temporary employees with* ***USGS COGEOMAP funds.***

1984-85

Capps, R.C., Reynolds, S.J., Kortemeier, C.P., Stimac, J.A., Scott, E.A., and Allen, G.B., 1985, Preliminary geologic maps of the eastern Big Horn and Belmont Mountains, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-14, 26 p., 2 sheets, scale 1:24,000.

Allen, G.B., 1985, Economic geology of the Big Horn Mountains of west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-17, 140 p.

1985-86 and 1986-87

Capps, R.C., Reynolds, S.J., Kortemeier, C.P., and Scott, E.A., 1986, Geologic map of the northeastern Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 86-10, 16 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., 2 sheets, 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.

Wahl, D.E., Reynolds, S.J., Capps, R.C., Kortemeier, C.P., Grubensky, M.J., Scott, E.A., and Stimac, J.A., 1988, Geologic map of the southern Hieroglyphic Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 88-1, 6 p., scale 1:24,000.

1987-88

Demsey, K.A., 1988, Quaternary geologic map of the Salome 30 x 60-minute quadrangle, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 88-4, scale 1:100,000.

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.

Demsey, K.A., 1988, Geologic map of Quaternary and upper Tertiary alluvium in the Phoenix North 30' x 60' quadrangle, Arizona: Arizona Geological Survey Open-File Report 88-17, scale 1:100,000.

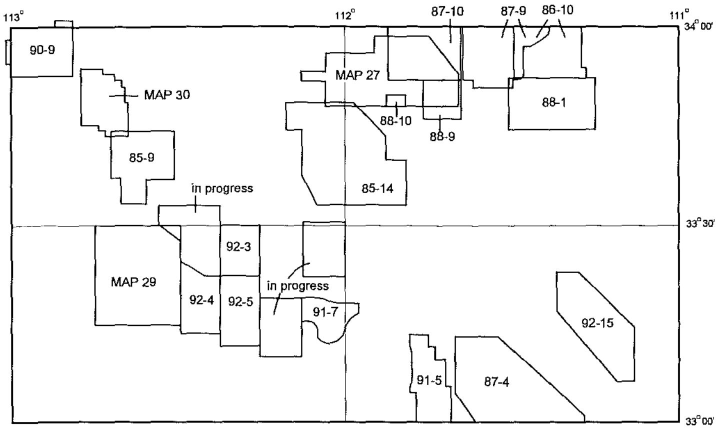
1988-89

Grubensky, M.J., 1989, Geologic map of the Vulture Mountains: Arizona Geological Survey Map 27, 3 sheets, scale 1:24,000.

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

Demsey, K.A., 1990, Geologic map of Quaternary and upper Tertiary alluvium in the Little Horn Mountains 30' x 60' quadrangle,

__Figure 2.__ Index map of all bedrock geologic maps within the Phoenix 1° x 2° quadrangle that were produced as part of the COGEOMAP program. Numbers refer to publications within the AZGS Open-File Report series, unless identified as publications within the AZGS Map series (e.g., Map 30).



Arizona: Arizona Geological Survey Open-File Report 90-8, scale 1:100,000.

1989-90

Grubensky, M.J., and Demsey, K.A., 1991, Geologic map of the Little Horn Mountains 15' quadrangle, southwestern Arizona: Arizona Geological Survey Map 29, 10 p., scale 1:62,500.

1990-91

Gilbert, W.G., 1991, Bedrock geology of the eastern Gila Bend Mountains, Maricopa County, Arizona: Arizona Geological Survey Open-File Report 91-5, 13 p., scale 1:24,000.

Scott, E.A., 1991, Geologic map of the central Gila Bend Mountains, west-central Arizona: Arizona Geological Survey Open-File Report 91-7, 11 p., scale 1:24,000.

Northrup, C.J., and Reynolds, S.J., 1991, Proterozoic geology of the Webb Peak area, northeastern Gila Bend Mountains, southwestern Arizona: Arizona Geological Society Digest 19, p. 251-259 (includes map, approximate scale 1:24,000).

1991-92

Gilbert, W.G., and Spencer, J.E., 1992, Geology of Cemetery Ridge, Clanton Hills, and westernmost Gila Bend Mountains, La Paz and Yuma Counties, Arizona: Arizona Geological Survey Open-File Report 92-4, 15 p., scale 1:24,000.

Gilbert W.G., Laux, D.P., Spencer, J.E., and Richard, S.M., 1992, Geologic map of the western Gila Bend and southern Eagletail Mountains, Maricopa and Yuma Counties, Arizona: Arizona Geological Survey Open-File Report 92-5, 16 p., scale 1:24,000.

Melchiorre, E.B., 1992, Geologic map of the Sierra Estrella, Maricopa County, Arizona: Arizona Geological Survey Open-File Report 92-15, 17 p., scale 1:50,000.

The following are __geologic maps__ of areas in or near the Phoenix 1° x 2° quadrangle that were produced largely or entirely by AZGS permanent employees with __AZGS COGEOMAP__ funds.

Reynolds, S.J., and Spencer, J.E., 1985, Reconnaissance geologic map of the Merrit Hills, southwestern Yavapai County, Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-5, scale 1:24,000.

Spencer, J.E., Richard, S.M., and Reynolds, S.J., 1985, Geologic map of the Little Harquahala Mountains, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-9, 18 p., 3 sheets, scale 1:24,000.

Spencer, J.E., Reynolds, S.J., Anderson, Phillip, and Anderson, J.L., 1985, Reconnaissance geology of the crest of the Sierra Estrella, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 85-11, 20 p.

Spencer, J.E., and Reynolds, S.J., 1986, Geologic map of the Lincoln Ranch Basin, eastern Buckskin Mountains, western Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 86-2, 6 p., scale 1:24,000 (superseded by AZGS Bulletin 198).

Spencer, J.E., Reynolds, S.J., and Lehman, N.E., 1986, Geologic map of the Planet-Mineral Hill area, northwestern Buckskin Mountains, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 86-9, 13 p., scale 1:24,000 (superseded by AZGS Bulletin 198).

Spencer, J.E., and Reynolds, S.J., 1987, Geologic map of the Swansea-Copper Penny area, central Buckskin Mountains, west-central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-2, 10 p., scale 1:12,000 (superseded by AZGS Bulletin 198).

Cunningham, Dickson, DeWitt, Ed, Haxel, Gordon, Reynolds, S.J., and Spencer, J.E., 1987, Geologic map of the Maricopa Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Open-File Report 87-4, scale 1:62,500.

Reynolds, S.J., 1988, Geologic map of Arizona: Arizona Geological Survey Map 26, scale 1:1,000,000.

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, 5 p., scale 1:24,000.

Reynolds, S.J., and Spencer, J.E., 1989, Pre-Tertiary rocks and structures in the upper plate of the Buckskin detachment fault, west-central Arizona, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, p. 67-102 (contains 8 detailed geologic maps).

Spencer, J.E., and Reynolds, S.J., 1989, Tertiary structure, stratigraphy, and tectonics of the Buckskin Mountains, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, p. 103-167 (contains 24 detailed geologic maps, including maps formerly released as AZGS Open-File Reports 86-2 and 87-2).

Spencer, J.E., Grubensky, M.J., Duncan, J.T., Shenk, J.D., Yarnold, J.C., and Lombard, J.P., 1989, Geology and mineral deposits of the central Artillery Mountains, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, p. 168-183 (includes detailed geologic map).

Spencer, J.E., Reynolds, S.J., and Lehman, N.E., 1989, Geologic map of the Planet-Mineral Hill area, northwestern Buckskin Mountains, west-central Arizona, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, Plate 2, scale 1:24,000 (formerly released as AZGS Open-File Report 86-9).

Spencer, J.E., 1989, Compilation geologic map of the Buckskin and Rawhide Mountains, west-central Arizona, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, Plate 3, scale 1:100,000.

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Spencer, J.E., and Reynolds, S.J., 1990, Geology and mineral resources of the Bouse Hills, La Paz County, west-central Arizona: Arizona Geological Survey Open-File Report 90-9, 21 p., scale 1:24,000.

Reynolds, S.J., Spencer, J.E., Laubach, S.E., Cunningham, Dickson, and Richard, S.M., 1991, Geologic map and sections of the Granite Wash Mountains, west-central Arizona: Arizona Geological Survey Map 30, scale 1:24,000 (supersedes map in AZGS Open-File Report 89-4).

Richard, S.M., 1992, Detailed geologic map of the upper Apache Wash area, central southern Plomosa Mountains, west-central Arizona: Arizona Geological Survey Open-File Report 92-2, 11 p., 2 sheets, scale 1:12,000.

Spencer, J.E., Gilbert, W.G., and Richard, S.M., 1992, Geologic map of the eastern Eagletail Mountains, Maricopa, LaPaz, and Yuma Counties, Arizona: Arizona Geological Survey Open-File Report 92-3, 12 p., scale 1:24,000.

*The following are **geologic reports** based on bedrock geologic mapping in west-central Arizona that was directly or indirectly related to the COGEOMAP program.*

Reynolds, S.J., Scott, E.A., and O'Haire, R.T., 1985, A fluorite-bearing granite, Belmont Mountains, central Arizona: Arizona Bureau of Geology and Mineral Technology Fieldnotes, v. 15, no. 2, p. 3-5.

Reynolds, S.J., Spencer, J.E., Richard, S.M., and Laubach, S.E., 1986, Mesozoic structures in west-central Arizona, *in* Beatty, Barbara, and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest 16, p. 35-51.

Spencer, J.E., and Reynolds, S.J., 1986, Some aspects of the middle Tertiary tectonics of Arizona and southeastern California, *in* Beatty, Barbara, and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest 16, p. 102-107.

Spencer, J.E., and Reynolds, S.J., 1986, Field trip guide to selected parts of the Harquahala, Granite Wash, and Buckskin Mountains, west-central Arizona, *in* Beatty, Barbara, and Wilkinson, P.A.K., eds., Frontiers in geology and ore deposits of Arizona and the Southwest: Arizona Geological Society Digest 16, p. 382-389.

Spencer, J.E., and Welty, J.W., 1986, Possible controls of base- and precious-metal mineralization associated with Tertiary detachment faults in the lower Colorado River trough, Arizona and California: Geology, v. 14, p. 195-198.

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Laubach, S.E., Reynolds, S.J., and Spencer, J.E., 1987, Mesozoic stratigraphy of the Granite Wash Mountains, west-central Arizona, *in* Dickinson, W.R., and Klute, M.A., eds., Mesozoic rocks of southern Arizona and adjacent areas: Arizona Geological Society Digest 18, p. 91- 100.

Richard, S.M., Reynolds, S.J., and Spencer, J.E., 1987, Mesozoic stratigraphy of the Little Harquahala and Harquahala Mountains, west-central Arizona, *in* Dickinson, W.R., and Klute, M.A., eds., Mesozoic rocks of southern Arizona and adjacent areas: Arizona Geological Society Digest 18, p. 101-119.

Reynolds, S.J., and Lister, G.S., 1987, Field guide to lower- and upper-plate rocks of the South Mountains detachment zone, Arizona, *in* Davis, G.H., and VandenDolder, E.M., eds., Geologic diversity of Arizona and its margins: Excursions to choice areas: Arizona Bureau of Geology and Mineral Technology Special Paper 5, p. 244-248.

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Spencer, J.E., Reynolds, S.J., and Welty, J.W., 1988, Control of mineralization by Mesozoic and Cenozoic low-angle structures in west-central Arizona: Society of Mining Engineers Annual Meeting, 117th, Phoenix, Ariz., Preprint Number 88-46, 4 p.

Reynolds, S.J., Richard, S.M., Haxel, G.B., Tosdal, R.M., and Laubach, S.E., 1988, Geologic setting of Mesozoic and Cenozoic metamorphism in Arizona, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States: Englewood Cliffs, N.J., Prentice-Hall, Inc., p. 466-501.

Roddy, M.S., Reynolds, S.J., Smith, B.M., and Ruiz, Joaquin, 1988, K-metasomatism and detachment-related mineralization, Harcuvar Mountains, Arizona: Geological Society of America Bulletin, v. 100, p. 1627-1639.

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Grubensky, M.J., 1989, Geology of post-detachment, Miocene volcanic rocks in the southwestern Buckskin Mountains, *in* Spencer, J.E., and Reynolds, S.J., eds., Geology and mineral resources of the Buckskin and Rawhide Mountains, west-central Arizona: Arizona Geological Survey Bulletin 198, p. 255-262.

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Spencer, J.E., and Reynolds, S.J., 1989, Overview of the geology and mineral resources of the Buckskin and Rawhide Mountains: Arizona Geology, v. 19, no. 2, p. 1, 6-11.

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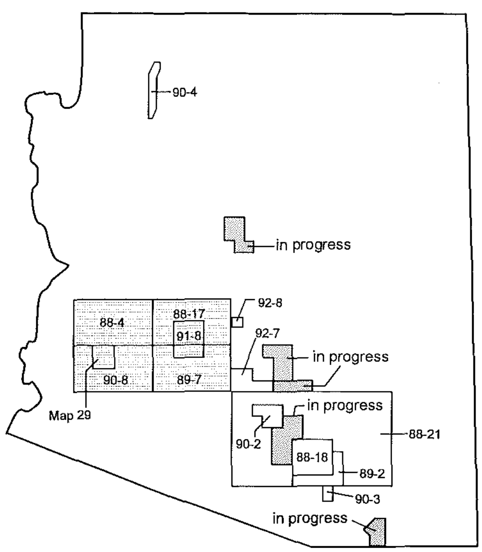

***Figure 3.** Areas within Arizona where the surficial geology has been mapped as part of the COGEOMAP program. Numbers refer to publications within the AZGS Open-File Report series, unless identified as publications within the AZGS Map series (e.g., Map 29). The darkly shaded areas are still being mapped. The lightly shaded rectangle is the Phoenix 1° x 2° quadrangle (see Figures 1 and 2).*

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Lite Geology Offers Light But Lively Reading

Lite Geology, a new quarterly publication by the New Mexico Bureau of Mines and Mineral Resources, presents geologic information in an easy-to-understand, fun-to-read format. This nontechnical newsletter is written for educators and members of the public who have an interest in earth science. Supporting educational activities, such as quizzes, games, and experiments, are included, as well as articles and news. For a free subscription, write to or call Susan J. Welch, Editor, *Lite Geology*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801; tel: (505) 835-5410.

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DRAGOON ***continued from page 2***

considered all such contacts to be thrust faults; in 1987, he reinterpreted one of these contacts as depositional. Many steep faults in the footwall block of the Fourr Canyon Fault were interpreted by Drewes as thrust faults. We felt that the evidence supporting this interpretation was equivocal, as was the evidence indicating which fault block was overthrust and which was underthrust.

As explained above, geologically complex areas, such as the Dragoon Mountains, are often interpreted differently by geologists. In many scientific fields, verification of experimental results is essential to their acceptance by the scientific community. Individuals should therefore view all geologic maps with skepticism until an area has been mapped by two or more geologists whose interpretations agree.

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Foster, D.A., and Spencer, J.E., 1992, Apatite and zircon fission-track dates from the northern Plomosa Mountains, La Paz County, west-central Arizona: Open-File Report 92-9, 11 p. $2.00

Fission-track thermochronologic data may reveal aspects of the timing, rate, and style of crustal-extension tectonics. This study analyzes fission tracks in apatite and zircon from samples of crystalline rock from a south-to-north transect across the northern Plomosa Mountains. The zircon and apatite apparent ages are concordant and indicate very rapid Miocene cooling of each sample location along the exposed footwall through the annealing temperature intervals for apatite (<120°C) and zircon (<200°C).

Richard, S.M., 1992, Bedrock geologic map of the Imperial Reservoir quadrangle, Yuma County, Arizona, and Imperial County, California: Open-File Report 92-11, scale 1:24,000. $2.00

Late Oligocene and early Miocene volcanic rocks overlie a variety of pre-Tertiary rocks in the Imperial Reservoir quadrangle. The volcanic rocks accumulated in the Ferguson Wash caldera and include four lithologically distinct ash-flow tuffs and interbedded mafic to intermediate lava. They were deposited on conglomerate correlated with the upper part of the Cretaceous(?) McCoy Mountains Formation and on Proterozoic(?) igneous and metamorphic rocks. No evidence of mineralization was noted in the area.

Richard, S.M., 1992, Geologic map of the Red Hill NE 7.5' quadrangle, La Paz and Yuma Counties, Arizona: Open-File Report 92-12, scale 1:24,000. $2.00

About 4,000 feet (1,250 meters) of late Oligocene and Miocene volcanic rocks crop out in the Red Hill and Red Hill NE quadrangles in the eastern Chocolate Mountains. No pre-Tertiary rocks are exposed. The stratigraphy is highly variable, but ash-flow tuffs correlated with the tuffs of Felipe Pass and Ten Ewe Mountain provide marker units. The volcanic rocks are overlain by gently dipping conglomerate with locally derived clasts. Untilted conglomerate caps the section. Normal faults related to the tilting of the Tertiary strata are cut by normal and strike-slip faults related to the formation of the present physiographic basins. Integration of the Colorado River resulted in deep dissection of the basin-fill conglomerates. No evidence of mineralization was noted in the area.

Moulton, D.L., 1992, DRASTIC analysis of the potential for groundwater pollution in Pinal County, Arizona, with a fissures study by Steven Slaff: Open-File Report 92-13, 67 p., 9 blueline sheets, scale 1:250,000. $25.00

DRASTIC is a system developed by the U.S. Environmental Protection Agency for evaluating the potential for groundwater pollution. The name "DRASTIC" is an acronym for seven hydrogeologic parameters: depth to water table, recharge to aquifer, aquifer media, soil media, topography (slope), impact of vadose (vadose media), and conductivity (hydraulic) of aquifer. Seven DRASTIC parameter maps were generated for this project, which was completed in cooperation with the Arizona Department of Environmental Quality and the Advanced Resource Technology Program of the University of Arizona. The DRASTIC process indicates that the potential for groundwater pollution in Pinal County is greatest along streambeds and in irrigated areas, and minimal in mountainous regions and where the depth to water is great.

Richard, S.M., 1992, Geologic map of the Red Hill 7.5' quadrangle, Yuma County, Arizona: Open-File Report 92-14, scale 1:24,000. $2.00

See description for Open-File Report 92-12.

Melchiorre, E.B., 1992, Geologic map of the Sierra Estrella, Maricopa County, Arizona: Open-File Report 92-15, 17 p., scale 1:50,000. $4.00

The Sierra Estrella is a rugged, northwest-trending range southwest of Phoenix that is composed almost exclusively of Proterozoic crystalline rocks. This report contains a map and accompanying rock-unit and mineral-deposit descriptions of the range. The project was funded by the U.S. Geological Survey COGEOMAP Program.

Skotnicki, Steve, 1992, Geologic map of the Sycamore Creek region, Maricopa County, Arizona: Contributed Map CM-92-D, scale 1:24,000. $3.50

This map covers an area of approximately 200 square miles on the western side of the Mazatzal Mountains, Sycamore Creek, and the Granite Mountain area west of the Mazatzal Mountains. The study area primarily consists of Proterozoic granitic and metamorphic rocks that are locally overlain by Tertiary volcanic and sedimentary rocks and cut by north- and northwest-trending, high-angle faults.

Melchiorre, E.B., and Clemens, D.M., 1993, Geology of the south-central Goldfield Mountains, Arizona: Contributed Map CM-93-A, scale 1:10,000. $2.00

This geologic map covers an area of approximately 10 square miles east of Mesa. Middle Tertiary volcanic rocks that cover most of the map area overlie Proterozoic crystalline rocks and are cut by many north- and northwest-trending, high-angle faults.

Chenoweth, W.L., 1992, Geology and production history of the Big Chief uranium mine, Navajo County, Arizona: Contributed Report CR-92-D, 8 p. $1.50

The Big Chief uranium mine was the least productive of the six mines located on the eastern flank of the Oljeto syncline in Monument Valley. This report describes the location, geologic setting, and production history of the Big Chief, whose orebodies were formed in a channel deposit in the basal portion of the Shinarump Member of the Triassic Chinle Formation. The report includes a map of the mine's underground workings. Most of the information in the report is from Atomic Energy Commission documents. ■

Arizona Develops New Seismic-Acceleration Contour Maps

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As the 1989 Loma Prieta earthquake near Santa Cruz, California, so poignantly showed, bridges and other highway structures are especially vulnerable to the ground shaking produced by seismic waves. Engineers have developed design standards to help prevent disasters like the collapse of the Nimitz Freeway and Bay Bridge in the San Francisco area. These standards are partly based on information from fault maps and seismic-acceleration contour maps.

Maps of **active faults** (those that have moved within the last several million years) show where large earthquakes have occurred. **Seismic-acceleration contour maps** show the force of ground shaking that facilities within a specific area may undergo during an earthquake. The contour lines drawn on seismic-acceleration maps define ground motion of a specific level that will probably occur within a specific time. The *longer* the time interval one chooses (e.g., 250 years vs. 50 years), the *stronger* is the ground motion that will likely occur.

In 1983, the American Association of State Highway and Transportation Officials (AASHTO) published *Guide Specifications for Seismic Design for Highway Bridges*. This manual contains a seismic-acceleration contour map of the United States that was developed by seismologist S.T. Algermissen of the U.S. Geological Survey (USGS). The acceleration contours for Arizona served as the basis for designing highway structures in the State that could safely withstand the effects of earthquake-induced ground motion.

The AASHTO map, however, was developed using data from more seismically active and more fully researched areas of the United States. This drawback is confirmed in the manual, which states that "no attempt [was made] to locate actual faults on the regionalization maps, and variation of ground shaking over short distances — about 10 miles or less — [was] not ... considered. Any such microzoning must be done by professionals who are familiar with localized condition[s]."

The AASHTO map did not reflect the detailed geologic features and seismic activity in Arizona, nor did it cover every area of the State. The acceleration contours for Arizona were heavily influenced by seismicity in the San Andreas fault zone in southeastern California, the Wasatch fault zone in Utah, and the 1887 Sonoran earthquake in northern Mexico. The map, however, did not fully consider the **seismic source zones** within Arizona. These are zones that are capable of producing earthquakes, including areas with discrete faults and areas with similar earthquake potential. It is also unclear whether the map incorporated local seismicity (e.g., earthquakes that occurred in Fredonia and Prescott in 1959 and 1976, respectively).

Because of these deficiencies in the AASHTO map, the Arizona Department of Transportation (ADOT) contracted with Geological Consultants of Phoenix in 1991 to develop a new fault map and new seismic-acceleration contour maps for Arizona. To achieve this objective, we located seismic source zones, defined the magnitude and frequency (recurrence rate) of earthquakes in these zones, and estimated how the seismic energy from these zones would attenuate (decrease with distance from the earthquake source) across Arizona.

We used published and unpublished reports, maps, and other scientific data to compile a database of faults and likely seismic source zones. We evaluated these zones using ground and airborne reconnaissance, interpretation of aerial photographs, and subsurface exploration of representative faults, such as the Big Chino Fault and Aubry Fault. We combined historical seismicity; locations of potentially active, neotectonic faults; and geomorphic, stratigraphic, physical, and tectonic parameters to define the seismic source zones of Arizona and surrounding areas.

As a result of this research, we identified 186 faults or **fault zones** (areas with discrete planar faults), as well as 21 **seismic source zones** (areas of unique seismicity and active geologic structures). We estimated recurrence intervals for earthquakes within each seismic source zone based on historical seismicity as well as geologic and seismotectonic data. These data included fault-slip rates, paleoseismology, and the relationships between fault length and earthquake magnitude. We used a USGS computer program to determine the **acceleration coefficient** (level of ground shaking) that has a 90-percent chance of *not* being exceeded within the next 50 years. These analyses, which incorporated new and refined geologic and seismologic data, were then used to develop a contour map unique to Arizona. We also compiled a second map that shows the areas in which the acceleration coefficient has a 90-percent chance of *not* being exceeded within the next 250 years.

We determined that ground-acceleration levels in the northwestern, north-central, and southwestern areas of Arizona are higher than those shown on the AASHTO map. The higher levels in the Grand Canyon, Flagstaff, and Prescott areas are due to the significant number of potentially active faults in that region. The higher level in the Yuma area is largely due to seismic source zones in California and Mexico that have high recurrence rates. In the southeastern part of Arizona (Bisbee and Douglas area), however, the ground-acceleration levels are significantly lower than previous estimates because the geologic analysis permitted relocation of historical earthquakes from within Arizona to areas south of the border. The results of the geologic studies also showed longer earthquake-recurrence intervals (more than 100,000 years) for a typical fault in southeastern Arizona. In the remaining parts of the State, the ground-acceleration levels are essentially comparable to those shown on the AASHTO map.

Using an AUTOCAD computer program, we plotted the fault and contour maps at a scale of 1:1,000,000 on an ADOT, digitally generated, geographic and roadway base map. The final 374-page report, *Development of Seismic-Acceleration Contour Maps for Arizona*, which was published in September 1992, documents the research, field investigations, and analytical methods used to compile the five maps. The report and maps may be purchased for $18.00 from the Engineering Records Section, Arizona Department of Transportation, 1655 W. Jackson, Rm. 112F, Phoenix, AZ 85007; tel: (602) 255-8216. ■

MARS OBSERVING IN ARIZONA: GEOLOGISTS CONTINUE A 100-YEAR TRADITION

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Arizona: A land of red rocks, dry river beds, lava flows, volcanic cones, deep canyons, sand dunes, dust storms, and even a meteor crater. Take away the cacti, lower the temperature by about 100°F, and drop the air pressure to stratospheric levels, and you might think you were on Mars. For nearly a century, scientists have come to Arizona to study our solar system's fourth planet.

In the beginning, there was Percival Lowell. Attracted by Arizona's clear skies and dry climate, he built his Flagstaff observatory in 1894, originally for the sole purpose of observing Mars. Lowell's 1895 book, *Mars*, speculated on the climate and geology of the red, desert planet. Seeing what he thought was a network of oases and canals, Lowell claimed Mars to be an abode of intelligent life. His proclamation was "a shot heard 'round the world"; the romance and mystery of Mars inspired several generations of fiction writers, scientists, and even the famous rocket engineers, Robert Goddard and Werner von Braun.

As Lowell Observatory approaches its centennial, a new era in the exploration of Mars has opened. As you read this, NASA's *Mars Observer* spacecraft is speeding toward an August 24, 1993, rendezvous with the Red Planet. In December 1993, its seven instruments will begin mapping the planet from an average altitude of 400 kilometers (250 miles). Two of these instruments, the Gamma Ray Spectrometer (GRS) and the Thermal Emission Spectrometer (TES), are being controlled by investigators at the University of Arizona (UA) in Tucson and Arizona State University (ASU) in Tempe.

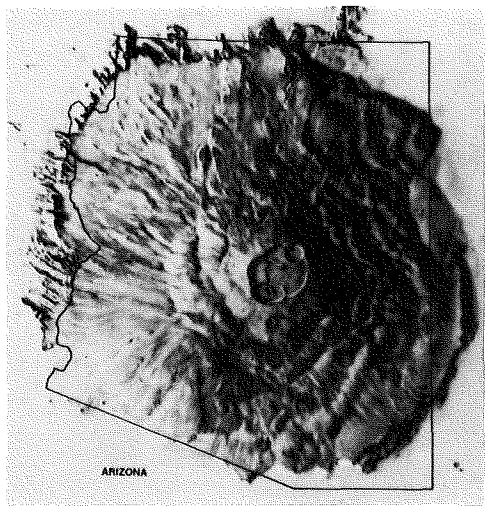


Figure 1. Mars' giant basaltic shield volcano, Olympus Mons, would completely bury Arizona. This figure was prepared by Phoenix resident Stephen P. Meszaros. NASA #83-H-246. Figures 1, 2, and 3 may be obtained from the National Space Science Data Center, Code 933, Goddard Space Flight Center, Greenbelt, Maryland 20771.

Launched on September 25, 1992, *Mars Observer* is expected to provide detailed observations of the planet's geology and will monitor seasonal changes in climate over an entire Martian year (687 Earth days). The project will extend at least through November 1995. *Mars Observer* is unique among NASA planetary exploration programs. For the first time, the science instruments will be controlled at the home institution of each science-team leader. Raw data from *Mars Observer* will be sent by radio from Mars orbit; received by dish antennas in California, Spain, and Australia; and then transmitted through the Jet Propulsion Lab in Pasadena, California, to the individual instrument teams at their home bases. The teams can send commands to their instruments by these same steps in reverse. The GRS and TES will be controlled in this manner from facilities at UA and ASU, respectively.

The science-team leader for the GRS is William V. Boynton, UA professor of planetary sciences. Designed to determine the elemental composition of the Martian surface at a resolution of about 300 kilometers (200 miles), the GRS measures the intensity of gamma radiation being emitted from the planet. Such radiation is produced by the natural decay of radioactive elements and the interaction of cosmic rays with the surface. The GRS can also detect thermal neutrons, which indicate the presence of hydrogen in water and ice buried to depths of up to 1 meter (3.25 feet). Considerable geomorphic evidence, such as lobate flows resembling terrestrial rock glaciers and crater ejecta patterns that look like mud flows, suggest that the Martian **regolith** ("soil") contains ice. Scientists will now have the opportunity to determine whether this ice is close to the surface or more deeply buried.

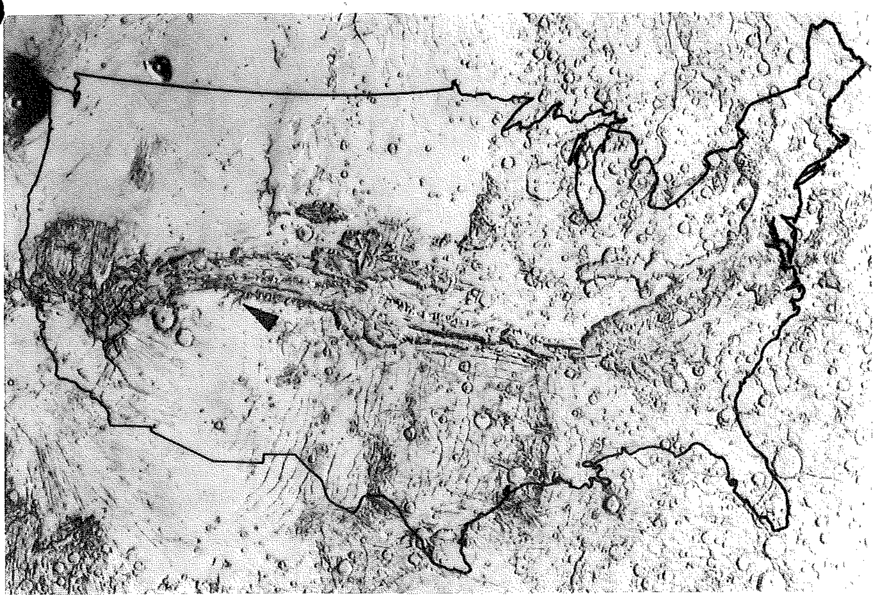
The principal investigator for the TES experiment is Philip R. Christensen, ASU professor of geology. From a geologic perspective, the TES will be a very useful instrument. Measuring infrared emission from the surface in wavelengths from 6 to 50 microns, the TES can detect the thermal vibrations made in the crystalline structure of minerals. Because each mineral type has a unique chemistry and structure, each vibrates at a unique frequency within the thermal infrared portion of the electromagnetic spectrum. The TES will map the mineralogical composition of the entire Martian surface at a resolution of about 3 kilometers (2 miles). TES data will also provide information about the grain size of surface sediments, monitor the particle size and quantity of dust suspended in the atmosphere, and observe the seasonal growth and retreat of the Martian polar caps.

The teams of scientists involved in the GRS and TES projects will travel from various parts of the United States, Russia, and Europe to UA and ASU during the *Mars Observer* mission. The science teams will plan observation sequences and analyze incoming data. In addition, scientists under the direction of Laurence A. Soderblom of the U.S. Geological Survey, Astrogeology Branch, in Flagstaff will integrate *Mars Observer* data with those from previous *Viking* and *Mariner* missions to see how the planet has changed during the nearly 30 years since the first spacecraft flew by the Red Planet.

Mars Observer continues a tradition of Martian studies conducted in Arizona since Percival Lowell first arrived in Flagstaff. Astronomers and geologists at Lowell Observatory and UA still turn their telescopes toward Mars every 2 years when the planet makes its closest approach to Earth. The most recent close approach occurred in January 1993; the next one will be in February 1995.

Some of the most amazing attributes of Mars concern scale. Mars is 6,790 kilometers (4,210 miles) in diameter;

Figure 2. The vast canyon system, Valles Marineris, named for its Mariner 9 *discoverer, would stretch across the entire United States. A tributary the size of Arizona's Grand Canyon is indicated by the arrow. Figure by S.P. Meszaros. NASA #84-H-595.*



Earth is 12,756 kilometers (7,909 miles) in diameter. Though only about half the size of Earth, Mars has considerably larger landforms. When Martian features are compared to similar features in Arizona, this inversion of scale is readily apparent. San Francisco Mountain, a composite volcano near Flagstaff, is 3.9 kilometers (12,633 feet) high and 12 kilometers (7.5 miles) in diameter. Olympus Mons, a basaltic shield volcano on Mars, is 25 kilometers (81,840 feet) high and 600 kilometers (370 miles) in diameter — a landform so large it would cover the entire State of Arizona (Figure 1). The vast Martian rift system, Valles Marineris, forms a canyon that would stretch from Los Angeles to New York. The Grand Canyon of Arizona would be a mere tributary to the Martian version, which is also four times deeper than the Grand Canyon (Figure 2). Arizona's famous Meteor Crater would be small as Martian craters go (Figure 3); however, because both Earth and Mars have atmospheres, geologists have found Meteor Crater's eroded rims and ejecta deposits to be a useful analog to the craters on our red-hued neighbor.

Arizona has a rich heritage in planetary studies. To learn more about Arizona's Mars connections, visit the Lowell Observatory in Flagstaff, where tours and open-house events are conducted regularly. The observatory features Percival Lowell's original telescopes and his hand-drawn Mars globes, complete with canals and oases. Also in Flagstaff, the U.S. Geological Survey's Astrogeology Branch is involved with all current NASA planetary projects and produces shaded-relief, topographic, and geologic maps of planetary surfaces.

In Tucson, UA's Lunar and Planetary Laboratory is the place to contact about the *Mars Observer* GRS project. The laboratory also serves as a NASA Regional Teachers' Resource Center for educators. UA's Flandrau Science Center and Planetarium features regular shows and displays about the planets and cosmos.

In the Phoenix area, ASU's Department of Geology has the *Mars Observer* Space Flight Facility, which was designed for the TES project. This facility has a visitor reception area with displays, videos, and tours that explain the *Mars Observer* and TES projects. Visitors to ASU are also encouraged to see the Center for Meteorite Studies, Geology Museum, and Space Photography Lab, all of which feature a variety of displays and information about planetary sciences.

As *Mars Observer* journeys toward the Red Planet, scientists are already planning for the next phase of Mars exploration, including launches in 1994 and 1996 by Russia, with an international contingent of orbiters, landers, rovers, and balloons. U.S. scientists are planning for the Mars Environmental Survey (MESUR), a program that would place a series of small landers on Mars beginning about 1998. NASA is considering a precursor mission, called MESUR-Pathfinder, for a 1996 launch. It is a sure bet that Arizona's experienced Mars science community will play a big role in these future endeavors, perhaps including onsite human explorations of the Red Planet sometime in the 21st century.

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Ken Edgett is a doctoral student of geology at ASU. In addition to conducting Mars research, he has helped to develop educational and public-outreach efforts for the *Mars Observer* TES project. Educators interested in workshops, tours, classroom guest speakers, and teaching materials should call the ASU *Mars Observer* Space Flight Facility at (602) 965-1790. For tours of ASU's other geologic facilities and displays, call the Visitor's Center at (602) 965-0100.

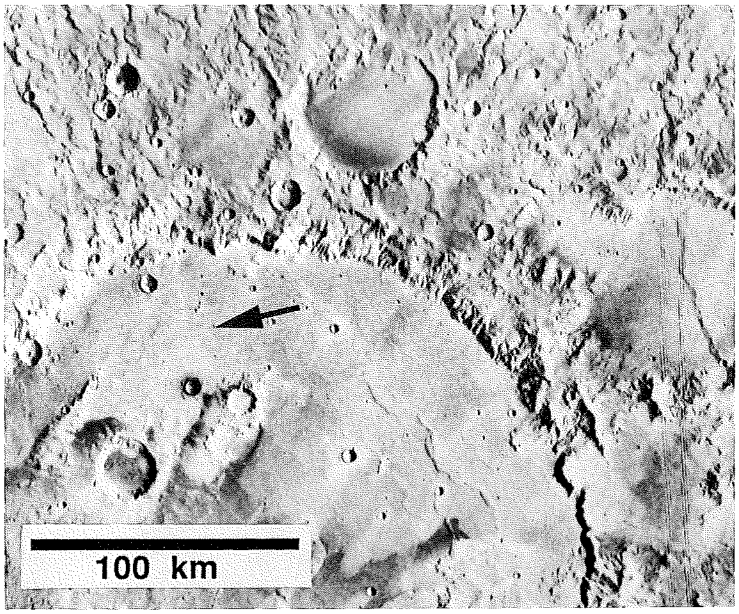

Figure 3. Craters within craters. The small impact crater indicated by the arrow is about five times larger than Arizona's Meteor Crater, yet looks tiny compared to the impact basin, Herschel, in which it lies. Viking 1 *image #629A26, taken in 1978.*

AZGS Now Sells AGS Publications

On December 17, 1992, representatives of the Arizona Geological ***Survey*** (AZGS) and the Arizona Geological ***Society*** (AGS) signed a Memorandum of Understanding (Figure 1), agreeing that the AZGS will be the distributor of AGS publications. The AZGS is a government agency charged by the State Legislature to research the geologic setting, mineral resources, and geologic hazards of Arizona, the results of which are published as maps and reports. The AGS is a nonprofit professional organization that holds monthly meetings, leads annual geologic field trips, and publishes maps and reports on Arizona's geology and mineral resources. Already linked because AZGS employees serve as AGS members and leaders, these two organizations have established a more formal bond with their new distribution agreement.

The following AGS publications may be purchased from the Arizona Geological Survey, 845 N. Park Ave., #100, Tucson, AZ 85719-4816. Orders are shipped by UPS; a street address is required for delivery. All orders must be prepaid by check or money order payable in U.S. dollars to the Arizona Geological Survey. Add these shipping charges to your total order:

Figure 1. *Anna Domitrovic (left), 1992 AGS President, and Rose Ellen McDonnell, AZGS Contract Specialist, shake hands on the signing of the AGS-AZGS Memorandum of Understanding, which makes the AZGS the distributor of AGS publications. Laurette Colton (center), AZGS Publication Sales Manager, observes.*

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AGS-1--*Arizona Highway Geologic Map,* by M.E. Cooley, 1967, scale 1:1,000,000. **$5.00**

AGS-3--*Southern Arizona Guidebook III,* edited by S.R. Titley, 1968, 354 p. **$12.00**

AGS-7--*Arizona Geological Society Digest,* 1964, v. 7, 171 p. **$5.00**

AGS-9--*Arizona Geological Society Digest,* 1971, v. 9, 265 p. **$6.00**

AGS-10--*Tectonic Digest,* edited by J.C. Wilt and J.P. Jenney, 1976, v. 10, 430 p. **$14.00**

AGS-13--*Arizona Geological Society Digest,* 1981, v. 13, 215 p., 2 sheets, scale 1:1,000,000. **$12.00**

AGS-14--*Relations of Tectonics to Ore Deposits in the Southern Cordillera,* edited by W.R. Dickinson and W.D. Payne, 1981, Digest, v. 14, 288 p. **$17.00**

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AGS-16--*Frontiers in Geology and Ore Deposits of Arizona and the Southwest,* edited by Barbara Beatty and P.A.K. Wilkinson, 1986, Digest, v. 16, 554 p. **$25.00**

AGS-17--*Geologic Evolution of Arizona,* edited by J.P. Jenney and S.J. Reynolds, 1989, Digest, v. 17, 866 p., scale 1:1,000,000. **$60.00**

AGS-18--*Mesozoic Rocks of Southern Arizona and Adjacent Areas,* edited by W.R. Dickinson and M.A. Klute, 1987, Digest, v. 18, 394 p. **$17.00**

AGS-19--*Proterozoic Geology and Ore Deposits of Arizona,* edited by K.E. Karlstrom, 1991, Digest, v. 19, 332 p. **$35.00**

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